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BUREAU OF MINES
R. R. SAYERS, DIRECTOR

INFORMATION CIRCULAR

# ANNUAL REPORT OF RESEARCH AND TECHNOLOGIC WORK ON COAL

## FISCAL YEAR 1945

BY

A. C. FIELDNER AND R. E. BREWER

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## Fiscal Year 1945[1]

By A. C. Fieldner[2] and R. E. Brewer[3]

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## INTRODUCTION

This is the tenth annual report of research and technologic work conducted by the Bureau of Mines on the occurrence, properties, mining, preparation, and uses of coal and coal products. These annual reviews are guides to the current work and publications of the Bureau but do not replace the more complete reports published under the authorship of the individual investigators on specific problems in Bureau of Mines bulletins, technical papers, reports of investigations, and information circulars and in the technical press. The Annual Report of the Director of the Bureau of Mines to the Secretary of the Interior for the Fiscal Year ended June 30, 1945, summarizes the year's work on coal as follows:

### Coal and Coal Products

The United States maintained its No. 1 industrial position in supplying fuel for war and in preparing for peace through more complete mining, improved preparation and up-grading of coal for special uses, and better utilization of coal in industrial establishments and homes.

Fuel Services. - To maintain fuel efficiency at military plants, to keep war industries operating at full capacity, to permit proper Government fuel purchases, to aid Federal coal-mine inspectors in preventing coal-dust explosions, and to assist the Bureau in coal explorations and research, 20,623 samples of various fuels were analyzed. Bureau engineers advised many Government agencies in the purchase and utilization of fuels and fuel-burning equipment; fuel efficiency and equipment acceptance tests were made. At many Army camps recommended changes in operation of equipment saved thousands of tons of coal. Choice of fuel was made for new Veterans Administration projects. Difficulties that prevented continuous boiler operation were eliminated at two naval land stations. Federal boiler plants, including all Army posts, were safeguarded from boiler-scale corrosion and caustic embrittlement through proper feed-water conditioning service. Serious corrosion in condensate return lines was studied, resulting in better protection of $300,000,000 worth of steel equipment.

National Fuel Efficiency. - A Nation-wide fuel-conservation program enlisting thousands of volunteer engineers and fuel users was conducted. A network of some 20,000 volunteers was established, and more than 13,000 industrial plants and organizations pledged cooperation aimed at saving 29 million tons of coal per year. Information on proper storing of coal was made available to industry by thousands of copies of publications. As a result of



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Bureau studies, a packaged-fuel plant was established in Philadelphia for converting 150,000 tons of surplus anthracite fines into a convenient fuel, and a large percentage of total fines was blended with bituminous coal for stoker use.

Coal Mining and Exploration. - The Bureau cooperated with anthracite producers in studying the prevention of flooding of operating mines and outlined new methods of better mining of thin, steeply pitching beds which constitute a large part of the anthracite yet unmined. Economic limitations of light equipment for stripping coal from outcrops in mountainous areas were determined. Western, southern, and eastern coal areas were explored for minable reserves of coking coals; the Pacific Northwest for near-by fuel supplies. Laboratory coking tests and petrographic examinations of more than 150 coals from the United States, Chile, and China were made. Methods of increasing efficiency and production of Chilean coals were investigated and reported.

Gas-, Dust-, and Vapor-Explosion Research. - To reduce explosion hazards in coal mines and in many types of plants, tests were made on industrial powders, dusts, and vapor-air mixtures; recommendations and safety codes were formulated for minimizing the destructive effects or preventing explosions in plants producing explosive materials and dusts; and specifications for conductive footwear and flooring materials were developed to lessen explosion hazards from static electricity. Conditions permitting safe use in coal mines of larger charges of explosives were determined by tests.

Coal Preparation and Storage. - To augment depleted supplies of high-grade coking coals and to up-grade marginal and lower-rank coals for more efficient utilization, preparatory treatments of coking coals to reduce sulfur and ash and the salvaging of refuse coal at points of mining were studied. The distribution of sulfur in coking coals of Greene County, Pa., was determined. Two Alabama companies based designs of coal-preparation plants on Bureau washability data; and studies by Bureau engineers showed that concentrating tables were effective for recovering coke breeze from dumps. Laboratory studies on the storage properties of about 35 coals were made; thousands of publications on methods of storing coal were distributed to industry by request.

Coal Combustion. - To study slag deposits on boiler tubes from melted coal ash, to provide information for improving the design of boiler furnace, and to improve their operating efficiency, the Bureau developed apparatus to measure the thermal conductivity of coal-ash slags. Fundamental data were accumulated by a study of over 200 ash analyses; and studies of slagging and atmospheric conditions around furnace walls demonstrated one cause of tube failure and lessened boiler outage. Burning characteristics of emergency fuels and of fuels produced by new processes were determined. For the first time in the United States, the electron microscope was used to determine surface area and size distribution of powdered coal.

Coking and Gasification. - The Bureau's tests for the complete evaluation of the gas- and coke-making properties of coals were applied to coals from



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newly developed fields. This work has greatly benefited the gas and coke industries and will continue to do so after the war. Greater production and improved quality of uniform coke without increased cost of capital or labor were reported at several coke plants by use of Bureau data on coal bulk-density control. Technical assistance given to beehive-oven and beehive-coke recovery operations enabled operators to produce more coke and maintain higher operating efficiencies. A method was developed for producing carbon monoxide of relatively high purity by burning pitch coke or petroleum coke with oxygen. The Nation's immense reserves of lignite were brought closer to industrial use through successful testing of a large retort for producing carbon monoxide and hydrogen from lignite by gasification. These two processes offer promise of a cheap source of materials for a multitude of purposes.

Synthetic Liquid Fuels. - The program authorized by the Congress in the Synthetic Liquid Fuels Act (Public Law 290) is underway, with construction started on the necessary buildings and equipment at three locations. Research and development work is going on meanwhile in temporary laboratories.

At Bruceton, near Pittsburgh, Pa., a plant is being built that will provide adequate facilities for research and development work on the hydrogenation and gas-synthesis processes for making gasoline and oil from coal. A staff of over 100, that will operate the Bruceton plant when ready, is now at work with facilities available at Pittsburgh. They are engaged in fundamental research, process development work, and engineering design. The work includes correlation of the activity of catalysts with physical properties as revealed by X-ray spectra and measurements of specific magnetization and surface area. Progress has been made in developing an internally cooled converter designed to reduce the steel requirements per unit of production to one-fifth or one-tenth of that required in present European equipment. The effects of variables, such as catalyst, temperature, and contact time, on primary liquifaction of coal by hydrogenation have been studied, and the experimental hydrogenation unit has been operated on a Bureau-developed process for the production of fuel oil from coal.

The demonstration plants using coal, which will produce 200 barrels of oil a day as compared to 1 to 2 barrels per day from the pilot plants, will be designed to incorporate the new developments and the best ideas obtained from a recent study of European synthetic oil plants. Detailed information on 206 proposed sites in 21 States for the hydrogenation and gas-synthesis demonstration plant has been obtained and the data tabulated and analyzed. War plants suitable for conversion to synthesis plants have been included in this study.

A laboratory for research and development work on oil shale is under construction at Laramie, Wyo. The program to obtain fundamental data on oil shale needed for the design of experimental and demonstration plants for producing marketable products from oil shale is going forward in temporary quarters. Among the processes being investigated is the so-called thermal solution process in which the oil shale is heated to moderate temperatures (400° C.) in the presence of a solvent, such as shale oil, and then extracted with a more volatile solvent.

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Construction of the oil-shale demonstration plant on the Naval oil-shale reserve near Rifle, Colo., is progressing. The mine, which will provide 100 to 150 tons of shale per day for the retorts, has been opened. An important part of the mining operation will be to develop low-cost methods of mining oil shale and to demonstrate the costs of mining on a large scale. The processing section of the demonstration plant will have retorts of several types operating on a scale of 25 to 100 tons of shale per day each and equipment for refining the shale oil to produce salable products. Considerable equipment has been ordered and work on necessary roads, utilities, and housing is in progress.

## Explosives and Explosions

To avoid fires and explosions caused by exposure of bare electric trolley wire in mines, the Bureau of Mines has encouraged development of Diesel mine locomotives. A schedule of permissible requirements for such locomotives was published; if followed, the locomotive will be approved for use in gassy and dusty coal mines.

To permit heavier charges of explosives in coal mining and thus assist in meeting increased demands for coal, an extensive experimental study has developed conditions under which the permissible charge may be increased 1.5 to 3 pounds. A new schedule was published detailing the necessary conditions under which permissible blasting devices can be fired without stemming.

Fires and explosions in coal mines caused by explosives are reduced or prevented by the use of sheathed explosives, but under some conditions sheaths may cause toxic gas hazards to increase. Studies of such toxic gas emissions were maintained. Hazards associated with the use of liquid-oxygen explosives are being evaluated. New tests useful in this and studies of other explosives were developed.

A new test for detonators gave results more indicative of practice. An electronic chronoscope that will measure time intervals of a millionth of a second was invented.

Five explosives were added to the active list of permissible explosives, which now contains 178 names; 419 chemical analyses, 2,717 gallery tests, and 2,029 other control tests were made in connection with studies for the armed forces and in the maintenance of safe standards for mining.

## ACKNOWLEDGMENTS

This report includes work done under the technical direction of the following members of the staff of the Bureau of Mines:

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University of North Dakota.
University of Washington.

ORIGIN, COMPOSITION, AND PROPERTIES OF COALS

Inspection, Sampling, and Analysis

Owing to the coal shortage during the year, it was generally impossible to obtain bids on a guaranteed analysis basis, and in most instances Government agencies had to accept such coals as were offered or obtain coal through directives by the Solid Fuels Administration for War on a flat price basis. Consulting service, including the analyses of bids and recommendations of awards, was given on the purchase of fuel for the Department of Justice, the Office of Indian Affairs, the Federal Public Housing Authority, the Government Fuel Yards, the Veterans Administration, the Department of Agriculture, the War Department, and the Navy Department. Coal purchases by Federal agencies during the fiscal year were estimated at 11,000,000 tons; the War Department was the largest purchaser and the Navy Department the second largest. Analyses were furnished all purchasing agencies for use in evaluating coal



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bids and for use when substitute coals were offered. In connection with contracts for furnishing this coal, 6,516 reports on proximate or ultimate analyses and heating value of coal and 2,366 reports on fusing temperatures of ash were issued to Federal agencies. Although no price adjustments were provided in the contracts, the War Department was supplied with analyses of reliable samples on which other action, such as cancellation of contracts, refusal of further shipments, and rejections of coal, could be taken. Coal sampling at Army posts, renewed in September 1943 upon request of the War Department, was continued, and Army personnel were instructed in proper methods of sampling. In all, 1,701 visits to Army posts were made, and 2,064 samples were collected. At the request of the War Department, a new program of collecting coals for spontaneous heating tests was started, and samples were collected at 27 mines in 11 States. Sampling at Pennsylvania anthracite breakers, initiated in November 1943 upon request of the Solid Fuels Administration for War, was continued, and 484 samples at 125 breakers were collected during the year. As a result of this work, a number of breakers were shut down, others installed new cleaning equipment, and the quality of anthracite shipped was improved generally. Coals were collected for special purposes from deposits in several States. The coals included 22 face samples at 13 mines and 10 samples at 9 mines for preliminary washing tests, with the object of increasing production in Maryland by utilizing lower-grade coals; 5 face and 5 column samples from 5 beds, and 50 special petrologic samples for the purpose of correlating coal beds and of determining carbonizing properties of coals in the vicinity of Ansted, Fayette County, W. Va.; 2 Pennsylvania anthracites to determine the effect of anthracite when blended with bituminous coal in coke making, and 77 samples at 74 mines in Colorado, 6 samples at 4 mines in New Mexico, 2 samples at 2 mines in Utah, and 2 samples in 2 mines in Wyoming for preliminary carbonization tests by a new process for carbonizing coal developed by the Bureau of Mines at Golden, Colo.

In connection with the inspection of coal purchased on specifications by Federal agencies, 6,491 samples from purchases, tipple, and breaker inspections were analyzed. More than 87 percent of these samples were for the War and Navy Departments and for the Solid Fuels Administration for War; the remaining 13 percent were for civilian agencies of the Government. In addition, 6,574 samples were analyzed for correlation with researches by various sections of the Bureau of Mines on the preparation and utilization of coal and coal products, by the Florida Geological Survey in its studies of peat, and by the Foreign Economic Administration in its investigations of Italian lignite and of Chinese coals. These 6,574 samples came from 22 States in this country; from Australia, China, and Italy; and from Brazil, Chile, and Columbia in South America.

Federal coal-mine inspectors submitted 7,558 samples of dust taken from the ribs, roofs, and floors in 956 commercial mines in 20 States. Analyses of these dusts gave data that were used in formulating corrective recommendations to mine operators.

In addition to services given to the several sections of the Bureau of Mines and to other Federal agencies in analyzing a total of 20,623 samples of coal, coke, char, briquets, tar, pitch, centrifuge residues, gasoline fractions,



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and coal-mine dusts, the Central Laboratory in Pittsburgh assisted other coal laboratories by sending them portions of recently analyzed samples to permit checking laboratory procedures and equipment. Samples were furnished to 19 American laboratories during the fiscal year.

Analyses of Tennessee and Georgia Coals

A compiliation[4/] of analyses of Tennessee and Georgia coals made by the Bureau of Mines was published and is another in the series of papers describing coals of individual producing States. The topography and geology of the coal fields, methods of mining, production, preparation, distribution, uses, and the relationship of mine samples to commercial shipments were discussed. Descriptions of mine, tipple, and delivered samples included chemical analyses, calorific values, classifications by rank, agglomerating indexes, fusibility of ash temperatures, true specific gravities, and sulfur forms. Detailed descriptions were given of the location, thickness of bed, nature of floor and roof, and partings of a number of typical mines in Tennessee and Georgia. Tennessee ranked ninth in production of bituminous coal in 1942, the output being 7,425,000 tons.

## Constitution, Properties and Analytical Methods

### Petrologic Studies of Coal and Rock Cores from Exploration Projects

Petrologic studies were made of all coal cores and associated rock obtained from exploration projects by diamond drilling. The projects included explorations for coking coal and fuel reserves in the Paonia-Somerset region in west central Colorado and in the Deep River coal field in central North Carolina; for coking-coal reserves in the Lookout Mountain coal field in northeastern Georgia and northwestern Alabama; and for fuel reserves in the Coaldale coal district, Esmeralda County, Nev., the Coos Bay coal field in southwestern Oregon, the Narraganset coal basin in Rhode Island, the Georges Creek coal field in western Maryland, and the Toledo lignite deposit in Lewis County, Wash. Detailed descriptions of the coal cores and associated rock were recorded to coordinate with other data obtained on these exploration samples. Studies of the plant microfossils from the coal were made of the Paonia-Somerset and Coos Bay coals to correlate individual coal beds. Results obtained by microscopic and megasopic methods characterizing the Coaldale and Paonia-Somerset coals have been compiled.

The occurrence and petrologic characteristics of the Willow Creek coal bed in southwestern Wyoming and of a coal deposit near Coaldale, Nev., were studied in connection with exploration projects (see Exploration of Coal Deposits, pp. 25 and 29). The Main Middle Willow Creek bed contained about 30 area percent of anthraxylon, 50 of translucent attritus, 18 of opaque attritus, and 2 of fusain. Microscopic studies indicated that the relatively

4/ Fieldner, A. C., Nelson, W. A., Toenges, A. L., Fraser, T., Crentz, W. L., Anderson, R. L., Bell, C. H., Snyder, N. H., Cooper, H. M., Abernathy, R. F., Tarpley, E. C., and Swingle, R. J., Analyses of Tennessee Coals (Including Georgia): Bureau of Mines Tech. Paper 671, 1945, 243 pp.



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inert behavior of opaque attritus gave rise to pebbly structure in the coke. Compositional deficiencies of this coal for metallurgical coke production might be improved by blending with a coking coal containing a high percentage of anthraxylon. Studies of the Coaldale deposit showed that the coal was exceptionally high in detrital minerals, particularly in feldspar, and would have little practicability for important production.

## Methods of Petrologic Study

A review was made of petrologic concepts and the methodology of quantitative petrology. A new method was devised with the objective of resolving coal into six primary components, without regard to lithology. The method should better characterize coals already prepared for market; its application will be tested further, using prepared fractions of commercial coal.

## Definition of "Typical" Coal

To determine how typical an individual coal may be from evaluation of its petrographic analyses, the average petrographic compositions of American coals of different age groups were calculated from data obtained in Bureau of Mines studies of the past 15 years. Table 1 summarizes these data, which tend to show a systematic variation in average composition. Since the data are based on micro preparations, which necessarily involve some loss of most friable materials, it is probable that the average values for fusain, in particular, may be somewhat lower than the true value for the coal beds. However, since all the coals were analyzed under the same conditions, the data should indicate rather accurately the relative amounts of components. The fact that Carboniferous coals have about twice as much opaque attritus and fusain as the generally lower-rank coals of Tertiery age may be of general significance in their utilization. For example, these two constituents are notably less amenable to liquefaction by pressure hydrogenation than is the remainder of the coal; furthermore, fusain may not be forming in present day peats in the same way as it did in the past.

TABLE 1. - Average petrographic composition of coals of different geological age

| Component | Geological age, area percent | | |
|---|---|---|---|
| | Carboniferous | Cretaceous | Tertiary |
| Anthraxylon..... | 53.0 | 46.8 | 51.7 |
| Translucent attritus. | 31.3 | 40.4 | 40.2 |
| Opaque attritus..... | 12.2 | 10.9 | 6.6 |
| Fusain..... | 3.5 | 1.9 | 1.5 |

## Petrology of Coal-Column Samples from Operating Mines

Studies of column samples from various coal beds have been evaluated with reference to the average data for coals of different age groups as given in table 2. Because of the great differences in type and rank, which probably indirectly account for additional differences in the petrologic entities reported, comparison of the lignite with the Carboniferous age bituminous coals must be made with reservation. Petrologic analyses of nine other column samples were completed, but reports have not yet been issued.



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TABLE 2. - Summary of petrologic values from coal-column studies

| Component area, percent 1/ | Noonan lignite, Divide County, N. Dak. | Pocahontas No. 6 (?) coal, Fayette County, W. Va. | No. 5 Block coal, Raleigh County, W. Va. | Coal at Nebo Hopkins County, Ky. | Western Kentucky coals | | | | Mannington (No. 6) coal, Hopkins County, Ky. |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | No. 14 coal, Hopkins County | No. 12 coal, Hopkins County | No. 11 coal, Hopkins County | No. 9 coal, Muhlenberg County | |
| Anthraxylon.. | 56.2 | 58.4 | 36.5 | 47.8 | 63.6 | 64.1 | 64.1 | 64.8 | 51.1 |
| Translucent attritus.... | 33.4 | 31.4 | 45.8 | 40.2 | 28.6 | 31.2 | 29.3 | 26.7 | 34.7 |
| Opaque attritus.... | 3.8 | 5.1 | 15.6 | 7.3 | 5.0 | 2.4 | 3.3 | 5.4 | 4.7 |
| Fusain..... | 6.6 | 5.1 | 2.1 | 4.7 | 2.8 | 2.3 | 3.3 | 3.1 | 9.5 |
| Ash, percent, as-received basis..... | 7.8 | 14.0 | 10.1 | 7.9 | 9.6 | 18.4 | 6.9 | 9.3 | 3.2 |

1/ Petrologic values reported on visible-mineral free basis; that is, coal omitting visible impurities.



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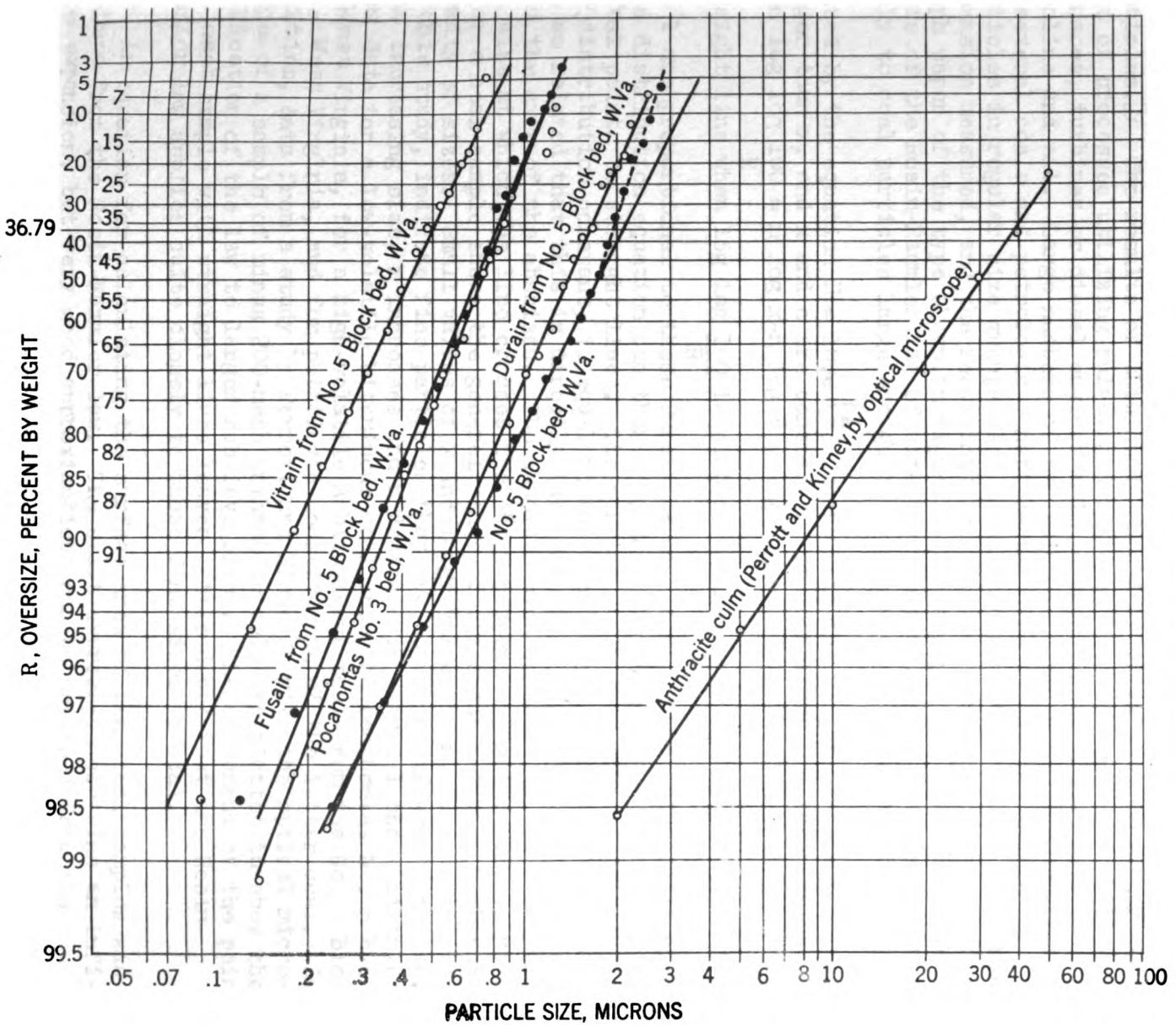


Figure 1. - Size distribution of subsieve coal particles.

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Electron-Microscope Studies of Coal and of Fischer-Tropsch Catalysts

The high resolving power of the electron microscope was used to determine the size distributions and surface areas of very finely crushed coal particles.5/ The results of this study should be of value in the improvement of processes utilizing pulverized coal, such as combustion in boiler furnaces, turbines or diesel engines and hydrogenation to form synthetic gasoline and oil. Large numbers of particles were measured on micrographs of several coals and petrologic constituents. The weight percentages of particles in regular size groups were calculated from the cube of the linear dimension measured, and the resulting distributions were plotted on special graph paper of the type shown in figure 1. This paper was devised on the basis of the Rosin-Rammler law of size distribution, which has been shown to apply to coal particles large enough to be measured by sieving. The law can be stated by the equation $R = 100e^{-\left(\frac{x}{\bar{x}}\right)^n}$ where R is the weight percent of sizes larger than x, and x and n are constants. If logarithms are taken twice, then $\log \log \frac{100}{R} = n \log x - n \log \bar{x} + \log \log e$. This is the equation of a straight line when $\log \log \frac{100}{R}$ is plotted against $\log x$. The scales in figure 1 are proportional to those functions of R and x. The suitability of this distribution equation can then be judged by the nearness of the experimental points to straight lines. The constant n in this equation, called the distribution constant, is equal to the slope of the line, and the scales are so related that this is directly the tangent of the angle of the line with the axis of the abscissa. The absolute size constant, $\bar{x}$, is equal to the size at which the line crosses the 36.79-percent ordinate. The value of $\bar{x}$ for a coal sample shows the general range of sizes and n varies with uniformity of sizes. Small values of $\bar{x}$ and large values of n, such as are found in this study, indicate fine particles that are not much different in size. With increasing size, $\bar{x}$ increases and n decreases. Figure 1 shows distribution data for a low-volatile bituminous coal from the Pocahontas No. 3 bed of West Virginia, for a high-volatile A bituminous coal from the No. 5 Block bed, West Virginia, and for petrologic constituents of the latter coal. In addition, data from a study by Perrott and Kinney6/ with the optical microscope of a sample of minus 200-mesh anthracite culm are plotted to show the application of the law to larger subsieve sizes. The agreement of the points for each sample with straight lines leaves little doubt that the Rosin-Rammler law applies quite closely to those fine sizes of coal.

An equation for calculating the surface area of fine coal samples was derived from the Rosin-Rammler law. The exact expression contains an infinite expansion, but very good approximations can be obtained from the

5/ McCartney, J. T., Determination of the Size Distribution of Fine Coal Particles by the Electron Microscope: Bureau of Mines Rept. of Investigations 3827, 1945, 11 pp.

6/ Perrott, G. St. J., and Kinney, S. P., The Meaning and Microscopic Measurement of Average Particle Size: Jour. Am. Ceram. Soc., vol. 6, 1923, pp. 417-439.



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following simplified form, $S = \frac{6}{\rho x}\Gamma\left(1 - \frac{1}{n}\right)$ where S is the area per gram, K and n are the Rosin-Rammler constants, $\rho$ is the density, and $\Gamma$ (the Greek gamma) is the symbol for a gamma function that can be found in statistical tables. The areas of the coal samples discussed were calculated by this equation, and the results are given in table 3. To show the suitability of this equation, the areas were also calculated from the average particle diameter, d, using the equation $S = \frac{6}{\rho d}$. An appropriate shape factor was applied to the measured particle dimension (x) to obtain a value of d suitable for use in this form of equation for area. Columns 5 and 6 of table 3 show the areas obtained by the two methods. This investigation shows that the complete size distribution and surface area of a sample of powdered coal can be obtained by using simple sedimentation or elutriation methods to determine the weight percent of particles above or below two or three sizes. The Rosin-Rammler line may be drawn from these data.

Fine coal particles, when subjected to high pressures, show tendencies toward plastic deformation. It appears that differences in the effects of these forces applied to particles of various ranks of coal are of such small magnitude that the high resolving power of the electron microscope is required to reveal the phenomena clearly. The method of applying the high pressure, with simultaneous observation of the sequence of effects, involves placing very fine particles of coal under a cover glass on a microscope slide, observing these under an optical microscope, and applying pressure on the flexible cover glass with a strong needle. Intermittent application of pressure attained by moving the needle back and forth or with a rotary motion is required. The coal particles under pressure are seen to flatten and spread. With some types of coal, a plastic flow ensues, which continues until the particle becomes a thin translucent film. Other coals, however, seem to disintegrate into much finer particles, and it is those that can best be studied in the electron microscope. This technique was applied to particles of vitrain and fusain selected from various ranks of bituminous and anthracite coal. Figure 2 shows electron micrographs illustrating the effect of high pressure on vitrain particles from a number of coals. Some evidence of plastic flow can be seen in all of these, but the greatest deformation occurs in the high-rank bituminous and in the semianthracitic coals. Coals of lower rank behave in the same general way but do not become as fluid. The anthracitic and meta-anthracitic coals tend to disintegrate into extremely fine particles. Fusain particles from a few coals showed similar differences, although the variations do not correlate regularly with rank of coal. Fusain from one subbituminous coal became fairly fluid, while that from another subbituminous coal behaved like vitrain from meta-anthracite, and fusain from a low-volatile bituminous coal reacted like an anthracitic vitrain. The significance of these differences in the effects of pressure has not yet been thoroughly analyzed. However, it appears that there are variations in the petrologic constituents, not readily discernible by usual optical means, that the electron microscope can help to reveal. Such differences may help to explain anomalies recently encountered in attempts to correlate petrologic character with degree of plasticity induced by heat in the coking process.



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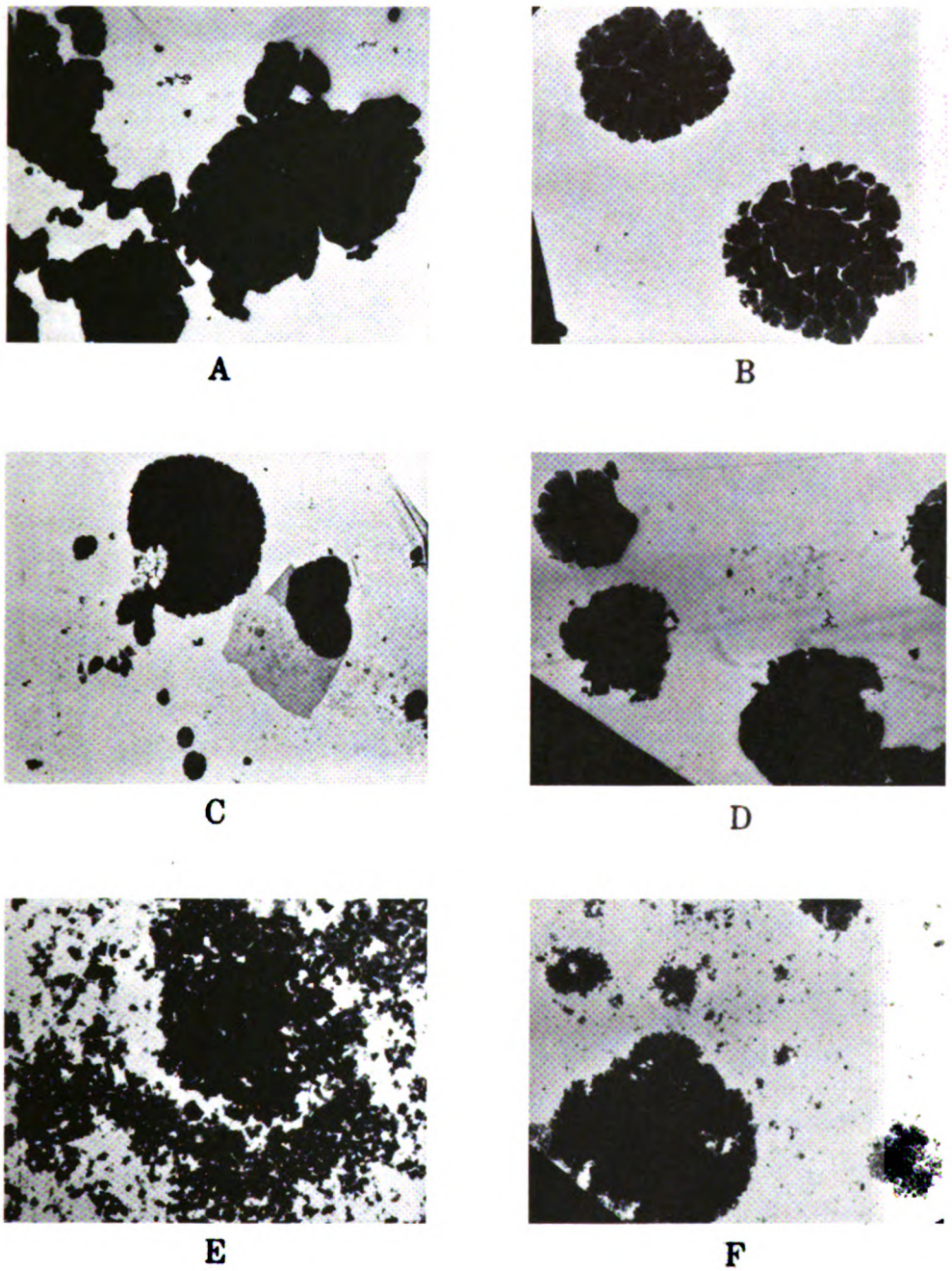


Figure 2. - Electron micrographs of compressed particles of vitrain from coals of various ranks: A, Subbituminous; B, high-volatile bituminous; C, low-volatile bituminous; D, semianthracite; E, anthracite; F, meta-anthracite. 2100X.

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TABLE 3. - Surface areas of fine coal samples determined by the electron microscope

| Coal sample | Density, gm. per cc. $\rho$ | Absolute size constant, microns $\bar{x}$ | Distribution constant n | Surface area, sq. m. per gm., calculated from | |
|---|---|---|---|---|---|
| | | | | Ave. diam. | Rosin-Rammler law |
| Vitrain from No. 5 Block bed coal.... | 1.3 (est.) | .50 | 2.13 | 30.9 | 36.5 |
| Fusain from No. 5 Block bed coal..... | 1.4 (est.) | .82 | 2.41 | 17.5 | 18.6 |
| Pocahontas No. 3 bed coal..... | 1.3 | .84 | 2.58 | 17.3 | 18.8 |
| Durain from No. 5 Block bed coal..... | 1.6 (est.) | 1.66 | 2.25 | 7.9 | 8.6 |
| No. 5 Block bed coal..... | 1.4 | 2.11 | 1.95 | 8.1 | 8.7 |
| Anthracite culm (optical microscope). | 1.8 | 38.8 | 1.45 | .36 | .58 |



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A catalyst used in the Fischer-Tropsch synthetic liquid-fuel process, consisting of cobalt oxide as the active unreduced catalyst, thorium oxide and magnesium oxide as promotors, and kieselguhr as a carrier, was studied by the electron microscope. Cobalt oxide and several types of kieselguhr were also studied. Figure 3 is a micrograph of the mixed catalyst. The large diatom with the regular pattern of round holes is characteristic of kieselguhr. Its effectiveness as a carrier is probably the result of this open structure, which permits the reacting gases to penetrate freely to the active ingredients. The particles and aggregates seen on the micrograph range in size from several microns down to 0.01 micron. Calculations from the effective surface area of this catalyst measured by a nitrogen-absorption method indicate that, if the material were composed of nonporous particles, their average diameter would be 0.015 micron or about the size of the smallest particle shown on the micrograph. Apparently the larger particles are either aggregates of these very small ones or are porous enough so that gases can readily penetrate them. Since calculations of surface area from electron micrographs depend on the visually apparent particle size, such measurements obviously would not show the area effective in catalyzing the Fischer-Tropsch synthesis. Measurements made on a number of micrographs of the cobalt oxide gave an area of 4 square meters per gram compared to 62 square meters per gram obtained by the nitrogen-absorption method.

Tests of Miscellaneous Materials

In addition to the 248 samples of coal that were tested in connection with the survey of their coking properties, 235 samples of miscellaneous materials, submitted by various sections of the Bureau of Mines or by others authorized to have analyses made, were analyzed and reported during the year. The samples represented a wide variety of materials from many sources. Thirteen boiler-water compounds and 30 boiler scales, sludges, or deposits were analyzed in connection with work on boiler feed-water conditioning to increase efficiency of boilers operated by the Government. Analyses of 47 external deposits from boiler and superheater tubes were made in connection with an investigation of the formation of external corrosive deposits. Phosphine was determined in acetylene produced from 18 samples of calcium carbide as a part of an investigation of the cause of explosions of acetylene generators in western shipyards. Chemical analyses were made of 14 coal or coke ashes, and phosphorous was determined in 15 samples of coal and coke. Sulfate was determined in 17 samples of alcohol and water solutions used in an investigation of a method of estimating surface moisture in crushed coal. At the request of the War Production Board, total iron was determined in the ash of 12 monthly composite samples of coke used in a Defense Plant Corporation blast furnace at Cleveland, Ohio. Determinations of silicon and iron in 8 samples of petroleum coke submitted by the War Department showed that the cokes would meet specifications for making carbon electrodes for the aluminum industry. The remaining 61 samples included rock-dusting materials, mine waters, soot removers, fly ash from furnaces, spent oil shale, residues from compressors in the coal hydrogenation plant, and catalysts used in the Fischer-Tropsch synthesis.



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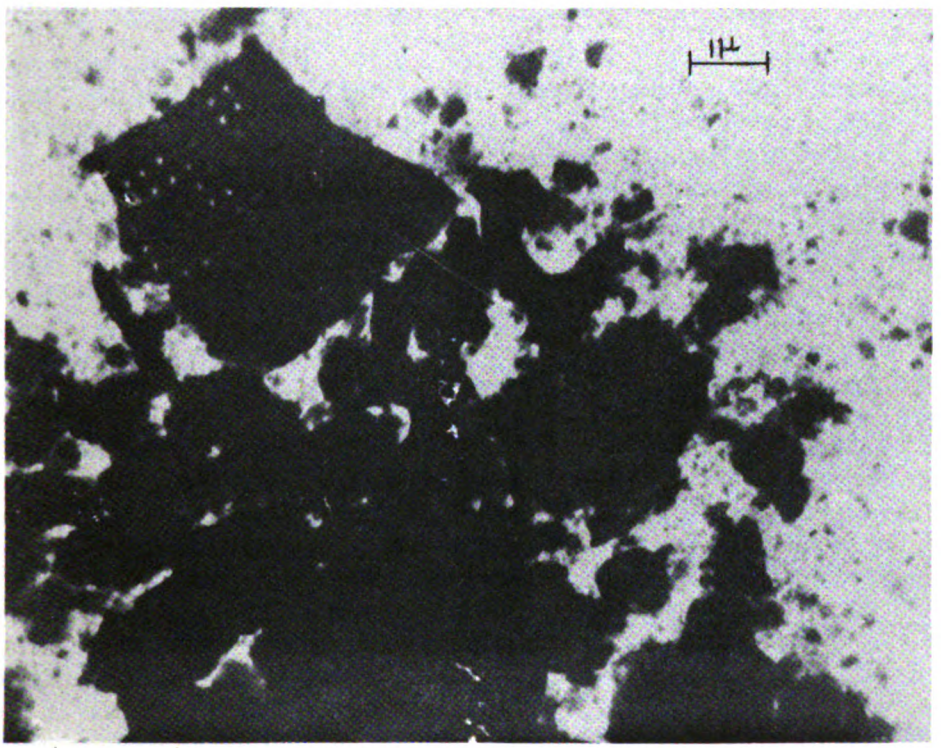


Figure 3. - Electron micrograph of cobalt oxide - magnesium oxide - thorium oxide - kieselguhr catalyst for Fischer-Tropsch synthetic liquid-fuel process. 11,300X.

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## Determination of Surface Moisture in Coal

Standard methods for determining total moisture in coal are time-consuming, and a knowledge of this moisture content is less useful than the surface-moisture content for control purposes in the coal and coke industry. Total moisture content of wet coal is considered to consist of two components, surface moisture and internal moisture. Presumably, the term "internal moisture" is synonymous with the inherent or bed moisture of coal saturated with moisture but containing no surface water. Surface moisture rather than either total or bed-moisture content controls primarily such physical properties of crushed coal as bulk density and angle of repose. In such processes as drying or dewatering coal in washeries, the real measure of accomplishment is the reduction in surface-moisture content.

To meet the need for a rapid, accurate method for determining surface moisture in coals, an experimental study was made which showed that surface moisture in high-rank eastern bituminous coals can be determined with satisfactory accuracy for most control problems by absorbing this moisture in a concentrated alcohol solution.1/ The method is based upon the change in specific gravity of alcohol caused by the absorption of water. Surface water dissolves quickly in alcohol, whereas the internal moisture is essentially unaffected. Usually 500 to 600 grams of coal, accurately weighed, and exactly 500 milliliters of alcohol are used in contact with each other for exactly 5 minutes. Specific gravity readings estimated to the fourth decimal place and temperature to the nearest 0.1° C. of the alcohol are determined experimentally before and after each test. The temperature correction for specific gravity is 0.0008 per °C. deviation from the base in the range ordinarily used in the tests. Percentages of alcohol by weight before and after the test are taken from a graph prepared from results of known mixtures of water and of the particular alcohol used, or, if the alcohol is of known purity, prepared from accepted data in published literature. The water absorbed by the alcohol is calculated as follows:

$$\text{Water from coal, grams} = V_i d_i \left(A_i/A_f - 1\right),$$

where $V_i$ is the initial volume of alcohol, in milliliters; $d_i$ is the initial density of the alcohol, in grams per milliliter, $A_i$ is the initial percentage by weight of alcohol; and $A_f$ is the final percentage by weight of alcohol.

The particle size of coal is not important as long as excessive amounts of very fine coal are not present. The alcohol can be used until it contains about 30 percent of water; the lowest limit has not been determined. Testing technique was developed so that the surface-moisture determination can be completed in less than 15 minutes. Alcohols, such as ethyl and isopropyl, are better than methyl for differentiating between surface moisture and internal moisture.

Correlations of the data obtained for surface moisture by this method on four coals as crushed for coke-oven charges with data for total moisture on the same coals as determined by the A. S. T. M. standard method, which uses a drying oven at 105° C. and a coal sample passing a U. S. Standard No. 60

1/ Schmidt, L. D., and Seymour, W., A Rapid Method for Determining Surface Moisture in Coal: Bureau of Mines Rept. of Investigations 3811, 1945, 11 pp.



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sieve, gave straight-line relationships. The total moisture in samples of the same coal, but of different moisture contents, can be closely approximated by addition of a constant to the determined surface moisture. This constant can be determined once for all for a given coal from the straight-line relationship found between surface moisture and total moisture. Preliminary studies of lower-rank bituminous and subbituminous coals have shown less constancy between the surface and total moisture contents, as determined by the two methods. In such coals the alcohol extracts some of the internal or bed moisture and gives high results for surface moisture. Research studies are being continued to enable a finer distinction to be drawn between surface and internal moisture, to improve the technique and precision on eastern coals, and to extend application of the method to lower-rank coals.

Analyses of Ash from Coals of the United States

Ash composition is a fundamental property of coal which determines its clinkering and slagging characteristics when burned on grates or in the form of powdered coal. Composition of ash is also important in the selection of coal for special purposes, such as cement manufacture and the burning of the finer grades of ceramic products. A compilation[8] of over 200 analyses of coal ash, including many ash-fusibility temperatures was made from Bureau of Mines laboratory records to show the ash composition of various coals of the United States. The report includes a discussion of the nature and occurrence of ash-forming mineral matter in coal and the relationships between ash composition and ash fusibility. Common mineral constituents determined in routine coal-ash analyses are given. Coal ash from coals of the United States varies widely in chemical composition but generally comes within typical percentage limits as follows: Silica, 20 to 60; aluminum oxide, 10 to 35; ferric oxide, 5 to 35; calcium oxide, 1 to 20; magnesium oxide, 0.3 to 4; titanium oxide, 0.5 to 2.5; sodium and potassium oxides, 1 to 4; and sulfur trioxide, 0.1 to 12.

Calorific Value of Coal

The calorific value of coal was discussed with reference to definitions, laboratory methods for its determination, formulas for calculating calorific value from coal analyses, the constancy of calorific value of coal in limited geographical areas, and its use as a basis for coal classification.[9]

Physical Properties of Coal

The hardness, strength, friability, and grindability of coal and methods of estimating these properties were reviewed, and the relationships of grindability of coal to rank and pulverizer performance were discussed.[10]

8/ Selvig, W. A., and Gibson, F. H., Analyses of Ash from Coals of the United States: Bureau of Mines Tech. Paper 679, 1945, 20 pp.

9/ Selvig, W. A., and Gibson, F. H., Calorific Value of Coal: Nat. Research Council (H. H. Lowry, ed.), Chemistry of Coal Utilization, New York, vol. 1, 1945, pp. 132-144.

10/ Yancey, H. F., and Geer, M. R., Hardness, Strength, and Grindability of Coal: Nat. Research Council (H. H. Lowry, ed.), Chemistry of Coal Utilization, New York, vol. 1, 1945, pp. 145-159.



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Resins in Coal

A summary[11] was prepared of available information on the nature, occurrence, and possible utilization of resins found in coal, with particular reference to western coals of the United States and Canada. Two forms of resins are visible in coal. One form, usually designated as a microscopic form of resin, is present in most coals. It is visible in thin section under the microscope and consists of small particles mixed with the coal so intimately that it cannot be removed by mechanical methods. The other form, designated as lump-type resin, is visible to the naked eye and can be recovered by crushing the coal and removing the separated resins by flotation methods. Some resinous western coals contain approximately 5 percent of these lump-type resins. According to published information, attempts have been made to evaluate lump-form coal resins for varnish making, and these indicate that coal resins as recovered from certain western resinous coals by flotation methods might be suitable for making the cheaper grades of dark varnishes. One investigator has reported that lump-form resins as recovered by flotation from resinous Utah coals contain waxes and asphaltic substances, which, if removed, give a purified resin suitable for making light varnishes.

## COAL MINING

### Experimental Mine and Dust Explosions

Technical Assistance and Service to Others

The Experimental Coal Mine and Dust Explosions Section assisted other sections of the Bureau of Mines, the War Department, and other Federal Agencies, and many national safety groups and industries. These activities included the preparation of coal for special tests by the Synthetic Fuels Division; lectures and demonstrations on dust explosibility and on mine-roof problems to groups of inspectors of the Coal Mines Inspection Division; assistance in designs of portable equipment for testing flame safety lamps, gas-flow equipment, and low-pressure manometers by the Safety Division and other sections; supplying of new information through reports on dust explosion research and assisting members of the Safety Division in miscellaneous field problems to facilitate plant inspections; and providing information to the Safety Division in connection with preparation of safety instruction manuals on coal mining. Consulting advice was given to military agencies on test methods and on precautions for preventing ignitions of various dust mixtures. Information was supplied to interested laboratories on special instruments used in dust-explosion studies, and to industrial companies on particle-size distribution and measurements and on means for reducing dust explosions. During the year an increasing number of technical men, some from foreign nations, visited Bureau laboratories to gather information on test methods and equipment.

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11/ Selvig, W. A., Resins in Coal: Bureau of Mines Tech. Paper 680, 1945, 24 pp.



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Studies of Coal-Mine Roof

The experimental project of roof sealing by means of a gilsonite-base paint in the Montour No. 10 mine of the Pittsburgh Coal Co. was inspected, and possible reasons for the ineffectiveness of the paint to prevent roof disintegration were analyzed. A wax-containing wetting agent was tested and found unsuitable as a roof-sealing medium. Tests were made of core-drill samples of shale from the immediate roof overlying the No. 7 Ohio coal bed in northeastern Ohio to provide data for predicting roof difficulties that might be encountered in a proposed mine. Assistance was given a railroad company on surface subsidence problems in connection with a railroad bridge to be erected over a coal-mining area. Information on roof-convergence problems and a recorder for testing were supplied to a group at Lehigh University working on the reduction of roof accidents in the anthracite field.

Allaying Dust in Coal Mines

Increased use of rubber-tired shuttle cars and other mining equipment in coal mines has emphasized the need of compacting or otherwise allaying the loose dust on the floor of mine roadways. The presence of such dust, ground to fine size by traffic and thrown into suspension in the air, constitutes an explosion hazard, is physiologically harmful, reduces visibility, and diminishes traction for the vehicles. Some mines have attempted to treat the dust with calcium chloride, which deliquesces when exposed to the mine atmosphere and thereby wets and consolidates the dust. To study the effectiveness of this procedure, Bureau engineers made tests in two operating mines and also investigated, under controlled laboratory conditions, the rate and extent of moisture absorption and the consolidation of mixtures of mine dust with calcium chloride, with commercial-grade, granular sodium chloride, and with samples of these salts that had been sprayed with wetting agents.

Figure 4 shows the rate of moisture absorption in air at 61° F. and 89 to 91 percent relative humidity by untreated calcium chloride and by calcium chloride treated with a wetting agent, and also by similar samples of sodium chloride. Figure 5 shows the rate of moisture absorption by a road-dust sample from one mine and by mixtures of the dust covered, with 1 and 3 percent untreated calcium chloride and of untreated sodium chloride, respectively. The principle conclusions from field and laboratory studies are: (1) In roadways of normally humid mines the loose dust can be consolidated effectively by proper application of 2 to 3 percent calcium chloride or sodium chloride; (2) in locations where the humidity is high - about 90 percent - sodium chloride is at least as effective as calcium chloride; and (3) untreated salts are as effective as salts which had been treated with wetting agents. A publication[12/] giving the details of the work just described was issued.

Laboratory tests were conducted to determine whether ordinary commercial-grade glycerin would be effective as a wetting agent for allaying coal dust

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12/ Thomas, E., and Hartmann, I., Use of Salts to Allay Dust on Shuttle-car Roadways in Coal Mines: Bureau of Mines Rept. of Investigations 3828, 1945, 15 pp.



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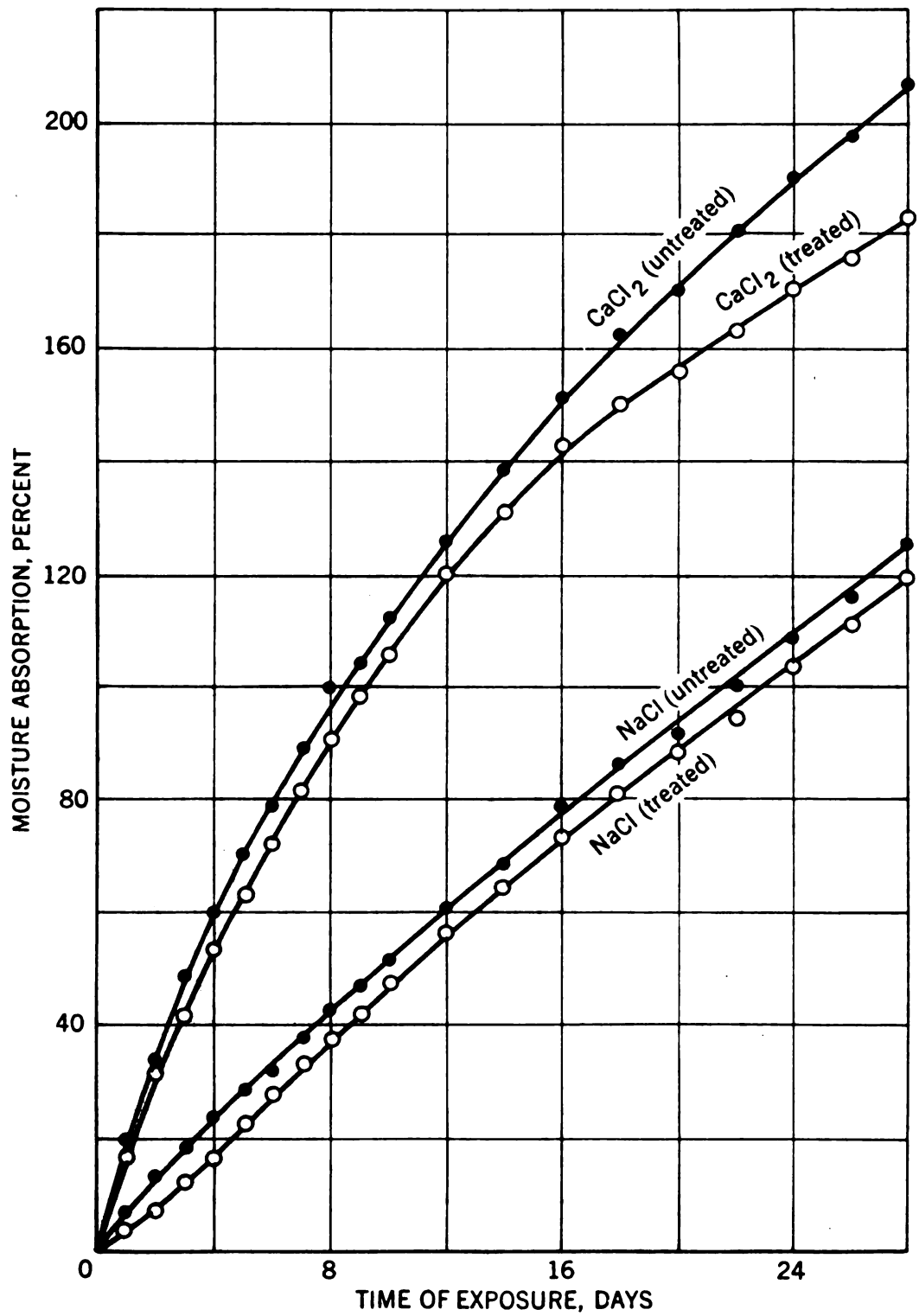


Figure 4. - Moisture absorption of calcium chloride and sodium chloride at 61 F. and 89 to 91 percent relative humidity.

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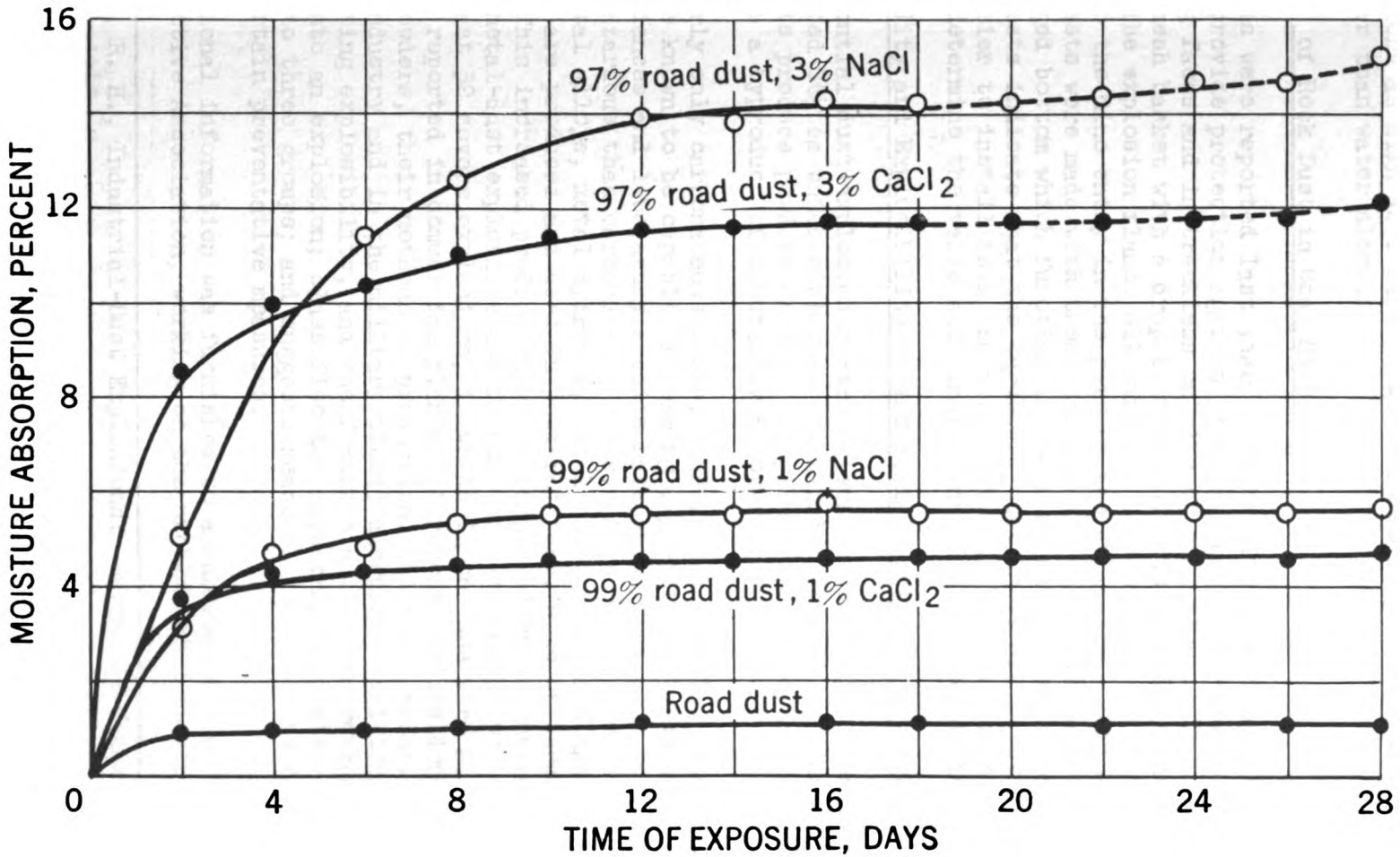


Figure 5. - Moisture absorption of No. 30 mine dust and untreated salt mixtures at 61 F. and 89 to 91 percent relative humidity.

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with water in mines. Coal dust is quite resistant to wetting by water alone. Concentrations as high as 1 part of glycerin to 10 parts of water proved to be no better than water alone.

Application of Rock Dust in Coal Mines

Results were reported last year of tests with an automatic device designed to provide protection against propagation of coal-dust explosions near the working faces and in trackless entries of coal mines. The device consists of a wire-mesh basket with a drop bottom, which is opened by the pressure wave preceding the explosion flame, allowing the rock dust in the basket to be dispersed into the mine entry in the path of the explosion. During the year additional tests were made with these baskets and also with cardboard containers with a hinged bottom which function in the same manner as the baskets. Preliminary tests indicate that the cardboard containers are about as effective and are easier to install than the wire baskets. Further tests will be required to determine the value and limitations of these two devices.

Inflammability and Explosibility of Industrial Dusts and Powders

A potential dust-explosion hazard exists in some 28,000 industrial plants in the United States which employ an estimated 1,000,000 persons.13/ Many of these plants produce powders or dusts as primary products, and in other plants the dust is a byproduct of manufacturing operations.

Formerly only carbonaceous dusts, such as coal, grain, sugar, and wood flour, were known to be capable of forming explosive mixtures with air. Recent experiences and laboratory studies have shown that some metal powders are more hazardous than carbonaceous dusts. At present, over 50 types of metals, metal alloys, metal hydrides, metal phosphides, and mixtures containing metals are produced and used in powdered form, some of them in huge amounts. This increased production was accompanied by an increase in the number of metal-dust explosions and fires. Between March 1939 and February 1944 at least 52 severe explosions, in which 19 persons were killed, were officially reported in commercial plants. A recent publication14/ lists the types of powders, their methods of production, and their principal applications in industry and in the military field; discusses ignition sources, factors affecting explosibility, and the fineness and concentration of the dust entering into an explosion; classifies the more than 100 metal-dust samples studied into three groups; and suggests means of reducing the explosion hazard through certain preventative measures.

Additional information was furnished to a subcommittee of the National Fire Protective Association, working on the problem of preventing dust

13/ Brown, R. H., Industrial-Dust Explosions: Bureau of Mines Inf. Circ. 7309, 1945, 7 pp.

14/ Hartmann, I., and Greenwald, H. P., The Explosibility of Metal-Powder Dust Clouds: Min. and Met., vol. 26, 1945, pp. 331-335.



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explosions in the plastics industry. These data are incorporated in the safety code[15] prepared by the subcommittee.

Material was prepared for a new book on Industrial Hygiene and Toxicology which is to include the subject, Explosion and Fire Hazards from dusts.[16]

New useful experimental data on dust explosibility were obtained during the year for 123 samples submitted by industries and military agencies. The samples included 34 metal powders and powders containing metals and their compounds, 24 food and other agricultural dusts, 22 incendiary, smoke, and other pyrotechnic mixtures used in chemical warfare, 18 powders used in the plastics industry, and coal, coke, rubber, and other dusts. Tests of 11 atomized aluminum powders of about equal fineness, submitted by 6 manufacturers through the War Production Board, showed that slight variation in manufacturing procedure or in purity of the powders had little effect on the explosibility of the final products. Comparison of test data for 3 atomized-magnesium and 1 atomized-magnesium-aluminum alloy powders with test data for milled and stamped powders of these metals showed that the atomized powders are the least explosive and the stamped powders most explosive, However, it must be kept in mind that atomization is a continuous process involving large quantities of powder at all times, whereas milling and stamping operations are generally performed with limited batches.

New Gallery Tests of Dust Explosions

The pressures developed by violent dust explosions in a confined space are so great that few manufacturing structures can withstand them without serious damage. One means for reducing such destruction is by providing, in the enclosing walls or roof, rapidly opening explosion-relieving devices or vents through which the pressure of an incipient explosion can be dissipated. To provide technical information on which the design of pressure-relief vents can be based and to furnish data on violent dust explosions, an extensive investigation of this problem was started. A 64-cubic foot gallery was designed and built, which has adjustable rectangular and square openings on three sides and on top, and in which dust explosions can be studied under controlled conditions. The gallery is housed in a shed 12 by 12 feet in area and 12 feet in height, whose sides are opened during tests. During the year, 377 explosion tests were made with dust clouds of pulverized coal, corn starch, soy bean protein, wood flour, phenolic resin, atomized aluminum, and stamped or flaked aluminum powder. In most tests no diaphragms or other restrictions were placed on the vent. Figure 6 shows an explosion of an atomized aluminum-powder dust cloud of 0.200 ounce per cubic foot concentration being vented through four openings having a combined area of 2.25 square feet or a relief ratio of 3.52 square feet per 100 cubic feet of volume of

15/ Jones, W. M., Forney, R. L., Hartmann, I., Hirst, H. S., and Merrill, J. W., Code for the Prevention of Dust Explosions in the Plastics Industry: Nat. Fire Protec. Assoc. Quart., vol. 38, pt. 2, April 1945, pp. 11-28.

16/ Hartmann, I., Explosion and Fire Hazard from Dusts: Industrial Hygiene and Toxicology (F. A. Patty, ed.), Interscience Publishers, Inc. (In press.)



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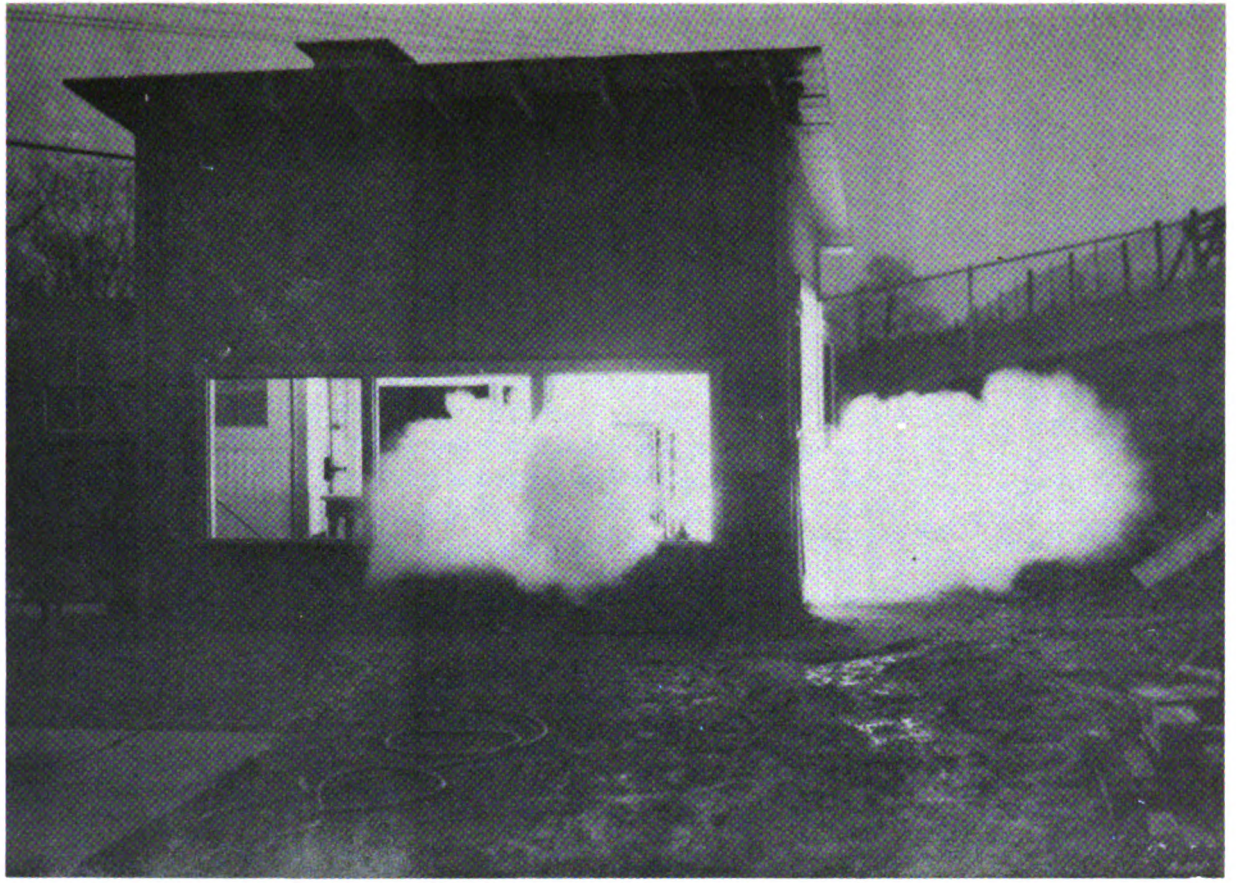

Figure 6. - Explosion of atomized aluminum-powder dust cloud in 64-cubic foot gallery vented through opening at top and on three sides of gallery.

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enclosure. Much of the interior of the shed surrounding the test gallery is obscured by the flame of the explosion. Most explosions were initiated by the flame of a small amount of guncotton, whose ignition was timed with the formation of the dust cloud; in other tests ignition was effected by a high-voltage induction spark. To date, the most violent explosions were developed by clouds of stamped-aluminum powder. To prevent the development of a pressure greater than 300 pounds per square foot with this powder, the unrestricted relief area had to exceed 7.5 square feet per 100 cubic feet. The same pressure reduction for wood flour and for pulverized coal could be accomplished with a relief-vent ratio of only 1.5 square feet per 100 cubic feet. A preliminary publication of the completed work is being prepared. Two additional galleries of different sizes have been designed and are under construction. Studies of various factors involved in this problem are being continued.

## Exploration of Coal Deposits

Exploration for coal deposits by Bureau engineers of the Coal Mining Section during the past fiscal year will be considered under two headings: (1) Coking coals, and (2) coal reserves in areas of critical fuel supplies.

### Coking Coals

The erection of steel plants in the West to augment production of steel for war made it advisable to seek additional nearby sources of coking coals. The only known source of metallurgical coal west of the Continental Divide available to these plants before the war was the Lower Sunnyside bed in Carbon County, Utah. The reserves in that area are reported to be extensive, but the outlet is restricted to one railroad which, if cut off for any reason, would seriously curtail steel production in western plants. Explorations therefore, were made in other western coal fields.

A reserve of high-volatile A bituminous coking coal was proved in Oyster Ridge, near Kemmerer, Lincoln County, Wyo. Results of the exploration, carbonization properties of the coal, and plans for development of this coal were published.17/

The area explored comprises 12 sections; except for a few small tracts, the coal and mining rights are owned by the Government. The southern limit of the area is about 3.5 miles north of the end of a standard-gage railroad and about 12 miles north of Kemmerer, a station on the Union Pacific Railroad. The thickness, physical characteristics, and extent of this Willow Creek bed coal and underlying and overlying strata were determined by 18 diamond-drill holes, which yielded 2-1/4-inch cores. Chemical and petrographic analyses (see p. 12)were made of these cores, and the dip and strike of the bed were computed from the drilling data. Two diamond-drill holes to recover 8-inch

17/ Toenges, A. L., Davis, J. D., Turnbull, L. A., and Schopf, J. M., Reserves, Bed Characteristics, and Coking Properties of the Willow Creek Coal Bed, Kemmerer District, Lincoln County, Wyo.: Bureau of Mines Tech. Paper 673, 1945, 48 pp.



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cores were drilled in proved areas to procure enough coal for large-scale carbonization tests at 900° C. The Willow Creek group is composed of Lower, Middle Main, and Upper (Rider) beds. The Middle Main bed, considered minable, averages 54 inches in thickness and dips west from the outcrop in Oyster Ridge into the Lazeart synclincal basin. The yields of carbonization products and the analyses and physical properties of the cokes were compared with corresponding data previously obtained by the Bureau of Mines on the Willow Creek bed, Gomer mine, coal and the Lower Sunnyside bed, Columbia mine, coal. In general, the shatter tests indicated that the Willow Creek cokes were as strong as the Lower Sunnyside coke, but in both the shatter and tumbler tests larger percentages of minus 1/4-inch coke resulted. Box coking tests of Willow Creek and Lower Sunnyside coals and of 60:40, 50:50, and 40:60 blends of these coals were made by the Columbia Steel Co. Results of the 50:50 blend indicated that this mixture would produce a satisfactory metallurgical coke based on Columbia Steel Co. standards. The coking properties of Middle Main Willow Creek coal can be improved by mechanical cleaning; partings in the coal bed cannot be effectively removed by hand. The exploration has indicated reserves of coking coal in three areas totaling 1,710 areas of surface. These reserves are estimated at 15,345,000 tons, of which 11,215,000 tons are considered recoverable. Physical conditions in and around the bed should not make mining problems too difficult, if modern mining practices are followed. The field can be opened in one area by the development of two mines at a cost of about $1,400,000, exclusive of road, railroad, and water supply, which are estimated at $330,000 additional. Mining costs under present conditions are estimated at $3.10 per ton. Figure 7 shows a proposed plan of development adaptable to conditions indicated by the exploration.

An area in Gunnison County, Colo., adjacent to Minnesota Creek was explored by diamond drilling. Ownership of the land is divided about equally between Government and private interests. Paonia, a station on the Denver & Rio Grande Railroad, is about 6 miles west of the area; a dirt road extends from Paonia to the southern boundary of the land. The terrain is very mountainous, and access to the area is difficult. Four diamond-drill holes yielded 2-1/4-inch-diameter cores. Chemical and petrographic analyses were made of the coal cores, and the dip and strike of the beds were computed from the drilling data. A diamond-drill hole to recover 8-inch coal cores was drilled in the proved area to procure enough coal for carbonization tests. These tests showed that the coal of Minnesota Creek is not suitable for making metallurgical coke. However, the exploration indicated large areas of recoverable coal available for industrial and domestic purposes.

A reconnaissance was made of coal areas in the Coal Creek district, Colorado - including the Grand Mesa, Mount Carbon, and Durango-Gallop fields. The results of this survey indicate that coal having coking qualities occurs in these fields. These areas are on the western slope of the Continental Divide and could serve as sources of supply of coking coal for western steel plants should exploration prove minable reserves, should carbonization tests show that the coke is suitable for blast-furnace use. One diamond-drill hole was drilled in the Coal Creek district, Grand Mesa field, in connection with the exploration of the Minnesota Creek area, Paonia, Colo. This drilling penetrated three minable coal beds. Table 4 gives the analyses of coal cores



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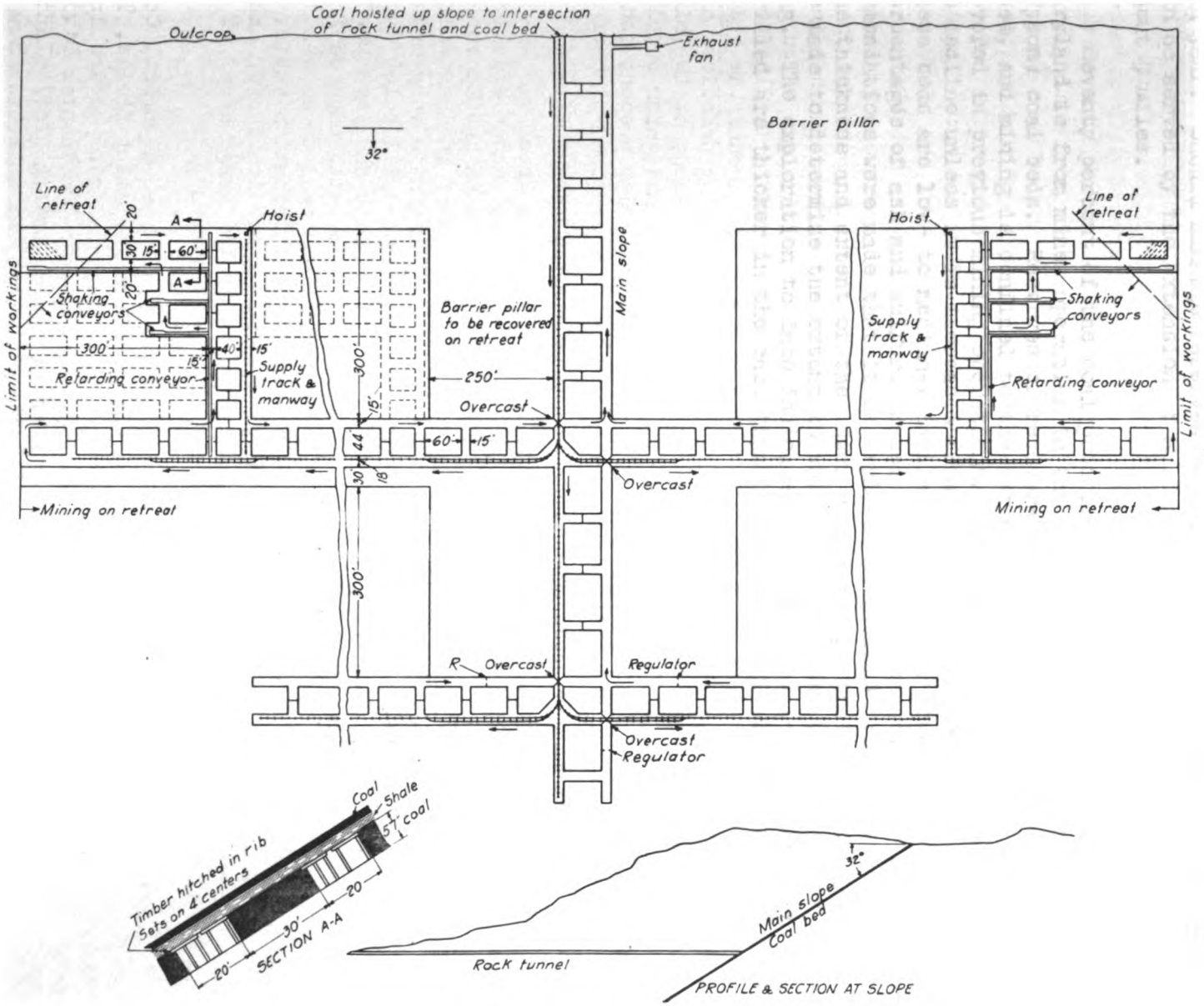


**Figure 7. - Plan of development adaptable to conditions indicated by exploration of Willow Creek-bed coal.**

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from the 2-1/4-inch hole and indicates that the coal has coking qualities. Further exploration of the Coal Creek area will be conducted during the coming year. Should minable reserves be proved, mines that may be developed can be served by the extension of a standard-gage railroad at a distance of about 5 miles.

Seventy percent of the coal produced in the Georges Creek coal basin in Maryland is from mines operating in the Pittsburgh (Big Vein) and Sewickley (Tyson) coal beds. Reserves of recoverable coal left in these beds are limited, and mining is confined to the extraction of pillars which were not recovered in previous mining operations. Production in this field is certain to decline unless it is increased from the lower, thinner beds. Coals from these beds are low- to medium-volatile coking coals, usually containing high percentages of ash and sulfur. Based on a reconnaissance of the field, recommendations were made that it be explored by diamond drilling to determine the thickness and extent of the lower coal beds and that washability tests be made to determine the extent to which the coals can be improved by washing. The exploration to date indicates that the coal beds in the area drilled are thicker in the east than in the west limb of the synclinal basin.



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TABLE 4. - Analyses of coal cores from Coal Creek district, Grand Mesa field

| Laboratory number | Conditions 1/ | Agglomerating index | Agglutinating value | Percent | | | | | | | | Calorific value, B.t.u. | Fusability of ash, °F. 2/ | | Bed |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Moisture | Volatile matter | Fixed carbon | Ash | Sulfur | Hydrogen | Carbon | Nitrogen | Oxygen | | | | |
| C-26870 | 1 | CF | 4.0 | 2.9 | 40.2 | 52.3 | 4.6 | 1.4 | 5.8 | 76.3 | 1.6 | 10.3 | 13,760 | 2,060 | ID | |
| | 2 | | | | 41.4 | 53.9 | 4.7 | 1.5 | 5.7 | 78.5 | 1.7 | 7.9 | 14,170 | 2,210 | S | A |
| | 3 | | | | 43.5 | 56.5 | - | 1.5 | 6.0 | 82.4 | 1.8 | 8.3 | 14,880 | 2,420 | F | |
| C-26950 | 1 | CF | 4.1 | 3.1 | 38.0 | 50.5 | 8.4 | .9 | 5.6 | 72.7 | 1.6 | 10.3 | 13,110 | 2,440 | ID | |
| | 2 | | | | 39.2 | 52.1 | 8.7 | 1.0 | 5.4 | 75.0 | 1.7 | 8.2 | 13,530 | 2,550 | S | B |
| | 3 | | | | 42.9 | 57.1 | - | 1.1 | 5.9 | 82.1 | 1.8 | 9.1 | 14,820 | 2,720 | F | |
| C-26952 | 1 | CF | 4.1 | 2.8 | 38.3 | 51.5 | 7.4 | .5 | 5.6 | 74.3 | 1.6 | 10.6 | 13,320 | 2,570 | ID | |
| | 2 | | | | 39.4 | 53.0 | 7.6 | .5 | 5.5 | 76.4 | 1.6 | 8.4 | 13,700 | 2,710 | S | C |
| | 3 | | | | 42.6 | 57.4 | - | .5 | 5.9 | 82.7 | 1.8 | 9.1 | 14,830 | 2,840 | F | |

1/ 1, Sample as received; 2, dried at 105° C.; 3, moisture-and-ash free.
2/ ID, initial deformation; S, softening; F, fluid.



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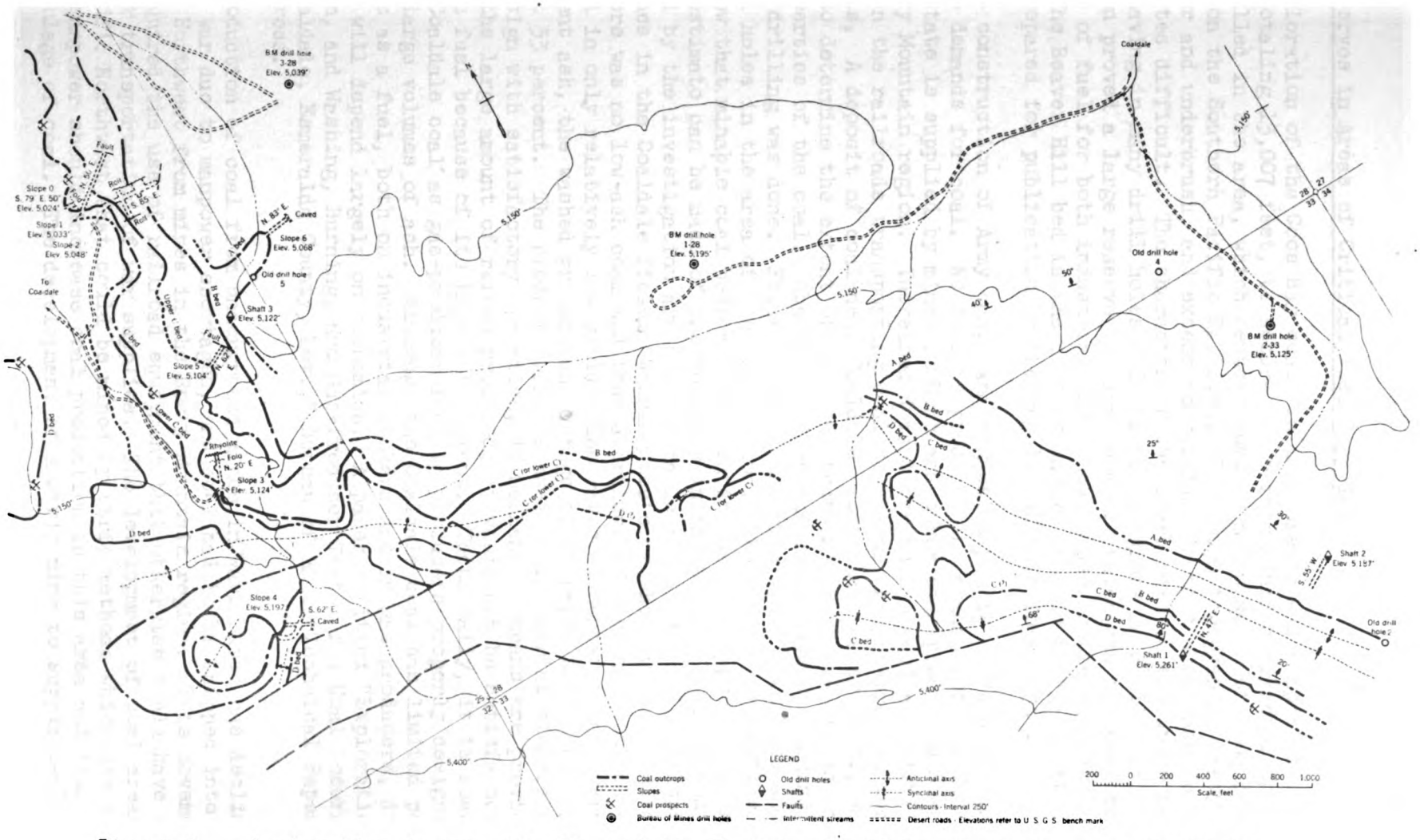


Figure 8. - Exploration in sec. 28, 29, and 33, T. 2 N., R. 37 E., M. D. M., near Coaldale, Esmeralda County, Nev.
(Prepared from map compiled by Geology of Fuels Section, Geological Survey)

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Coal Reserves in Areas of Critical Fuel Supplies

Exploration of the Coos Bay coal field in Oregon was completed. Fifteen holes, totaling 13,007 feet, to secure 2-1/8-inch minimum-diameter cores, were drilled in the area, which centers about 9 miles south of Coos Bay, a station on the Southern Pacific Railroad. The rough topography, heavy growth of timber and underbrush, and excessive rainfall in this area made access to drill sites difficult. The character of the overburden in the upper measures caused caving in many drill holes and delayed progress in drilling. The exploration proved a large reserve of minable coal, which can be developed as a source of fuel for both industrial and domestic use in the Pacific Northwest. The Beaver Hill bed is the most extensive in this area. A report is being prepared for publication on the results of this investigation.

The construction of Army camps and magnesium plants in Nevada resulted in large demands for coal. No coal is produced in Nevada, and the fuel used in the State is supplied by mines in Utah and other coal-producing States in the Rocky Mountain region. Increased demand for fuel placed an additional burden on the railroads transporting coal to the new Army camps and industrial plants. A deposit of coal near Coaldale, Esmeralda County, Nev., was explored to determine the extent of the coal beds and the character and physical properties of the coal. Abandoned mines and outcrops were examined, and diamond drilling was done. Figure 8 shows the outcrop of coal beds and sites of drill holes in the area of the exploration. The results of the investigation show that minable coal beds are not continuous over appreciable areas, and no estimate can be made of the reserves in these beds. Conditions as determined by the investigation are not favorable for successful development of coal mines in the Coaldale field. Washing tests of the raw coal indicated that there was no low-ash coal and that a product of high ash content can be obtained in only relatively low yield. The raw coal contained an average of 53 percent ash, the washed product an average of 35 percent ash and a yield of about 33 percent. The product could be used in industrial stokers of suitable design with satisfactory operation, if mechanical means are provided to handle the large amount of refuse produced; it would not be satisfactory as a domestic fuel because of its high ash content. Technically, it is feasible to use Coaldale coal as gas-producer fuel in producers properly designed to handle large volumes of ash. Although the Coaldale coal has limited possibilities as a fuel, both on industrial stokers and in gas producers, its suitability will depend largely on economics. A paper entitled "Exploration, Composition, and Washing, Burning, and Gas-Producer Tests of a Coal Occurring Near Coaldale, Esmeralda County, Nev.," Bureau of Mines Technical Paper 687, is in press.

Production of coal from underground mines in Washington has declined during the war due to manpower shortages, and coal had to be shipped into the Pacific Northwest from mines in the Rocky Mountain region. This movement of coal required the use of railroad equipment that otherwise could have been used for transportation of war supplies. The development of coal areas in the Pacific Northwest that could be mined by strip methods which use a minimum of manpower should increase coal production in this area and thus save long-haulage of coal. The development of a strip mine to supply coal demands



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at low cost requires a large investment in heavy equipment; to keep fixed charges due to large investment in the plant at a minimum, large reserves of coal must be proved. A reconnaissance of an area near Toledo, Lewis County, Wash., indicates a large reserve of lignite which could be mined by strip methods. This area is about midway between Portland, Oreg., and Seattle, Wash., and the opening of a large mine here would supply fuel to these centers. Explorations by diamond drilling in the Toledo area were still in progress at the end of the fiscal year. Work to date indicates the necessity for washing the coal. Preparation tests of this lignite will be discussed under Preparation of Coal on page 57.

Fuel requirements for industrial and domestic consumers in New England, in normal times, are supplied almost entirely by fuel oil, anthracite, and bituminous coal (a small amount of wood is burned in some localities). A shortage of these fuels occurred during the war. This shortage was caused by: (1) The diversion of oil to military uses; (2) the use of railroad and boat facilities for the transportation of war material; (3) the inability of coal mines to supply the increased demand for coal resulting from the conversion from oil to coal by domestic and industrial consumers; and (4) the increased demand of war industries for coal. Because of this critical fuel situation, an investigation was made of possible sources of fuel nearer the points of consumption in New England.

Meta-anthracite, which is a satisfactory fuel for some purposes, was mined in Massachusetts and Rhode Island many years ago. However, the introduction of better coal into New England markets resulted in the abandonment of these mines.

The coal from mines in the vicinity of Portsmouth on Aquidneck Island, Newport County, R. I., has been used successfully for smelting copper ore and for fuel. It is reported that this coal is less graphitic than the material mined at Cranston, near Providence, R. I. The coal is meta-anthracite and does not burn freely. However, improved equipment for burning coal has been developed and, should minable reserves of coal be found, methods of burning it probably could be devised.

The purpose of this investigation was to determine sources of additional fuel and as coal mined at Portsmouth had been used with some success, exploration was undertaken to determine the characteristics and continuity of the beds in this area.

Utilization investigations of the material mined at the Cranston mine of Graphite Mines, Inc., are being made by Rhode Island State College in cooperation with the Bureau of Mines.

The exploration, which was completed, did not disclose the presence of minable coal beds and the possibility of proving areas of coal that can be recovered by mining is not favorable. A report on the results of the investigation is being prepared.



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## Exploration by the Mining Branch

Of the 187 mineral deposits in the United States and Alaska explored by the Mining Branch of the Bureau of Mines during the fiscal years 1940-1944, 12 projects were concerned with explorations for coal.[18] The studies showed that the more important deposits of high-grade coals included estimated reserves of 2,500,000 tons of good coking coal near Fort Payne, Ala. (1,945,000 tons are considered recoverable); 15,345,000 tons of coking coal near Kemmerer, Wyo., (11,215,000 tons are considered recoverable), and a total of 3,332,200 tons of bituminous and subbituminous coals in three areas in Alaska. Subbituminous coal in two areas in Alaska - southwest of Fairbanks and in the Healy district - were being mined in 1944 under the supervision of the United States Army. The 3-million ton deposit of high-volatile B bituminous coal in the Moose Creek district, Alaska, was superior to any coal mined in the Matanuska field.[19] This is poorly coking coal but is in demand locally for domestic and commercial uses, particularly on stokers. The coal is amenable to open or closed storage, because it does not slack on exposure and its danger of spontaneous combustion is minimized by its low moisture and sulfur contents. The 1944 demand for coal in Alaska totaled 500,000 tons. By virtue of location, transportation advantages, and high quality of coal, the Matanuska field should supply 300,000 tons of the annual consumption. The activities of the lessees, together with the exploratory work by the Bureau of Mines, have made this production possible on the Buffalo Coal Co. leasehold for a minimum period of 10 years. Core drilling and trenching by the Bureau of Mines revealed a total of 2,375,500 tons of measured, indicated, and inferred coal in the Buffalo series, of which 1,656,700 tons are estimated as recoverable. Existence of deeper beds over the same length increased the estimated tonnage of coal of all categories to 3,259,300 tons. Exploration work on Alaskan coals is being continued by the Coal Mining Section of the Coal Division of the Bureau of Mines.

## Mining Methods and Practices

### Coal Strip Mining

The shortage of underground miners and the fact that more tonnage of coal can be produced per man by strip mining have stimulated increased activity in strip mining. Increased production of coal from strip mines in Kentucky, Maryland, Pennsylvania, and West Virginia has resulted largely from stripping operations in marginal deposits adjacent to outcrops in mountainous localities. Usually the reserves in these deposits are small and contractors' light equipment, such as tractor-scrapers and bulldozers, because of the comparatively small investment, is used instead of heavy equipment to remove the overburden in these areas. To determine the practicability of the methods in vogue and the economic limitations of this light equipment, studies were made of these operations. The studies are not yet complete and will be continued.

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18/ Julihn, C. E., and Moon, L. B., Summary of Bureau of Mines Exploration Projects on Deposits of Raw Material Resources for Steel Production: Rept. of Investigations 3801, 1945, 35 pp., esp. pp. 33-35.

19/ Apell, G. A., Moose Creek District of Matanuska Coal Fields, Alaska: Bureau of Mines Rept. of Investigations 3784, 1944, 36 pp.



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Hazards of Strip Mining

The rapid increase in the quantity of coal being mined by stripping methods has brought to attention the hazards connected with this type of mining. An important hazard exists in blasting in strippings adjacent to underground workings from the chance of carbon monoxide being drawn in. Where such conditions exist, blasting should be done only when all men are out of the workings and a thorough test should be made for dangerous gases underground before workers reenter.20/ Examples of the entrance of blasting gases into mines under these conditions are given, with the precautions instituted when the danger was recognized.

Mechanical Mining of Anthracite

To assist the anthracite industry to meet wartime demands for anthracite with a fixed manpower, investigations were made to increase the daily production per underground worker by two means: (1) Use of mechanical equipment and (2) application of mining methods previously untried in anthracite mining. Shortage of manpower, which has prevented the development of gangways in steeply pitching beds rapidly enough to provide sufficient working breasts, was relieved by a combination of a scraper slide with a shaker conveyor. This equipment enabled a complete cut of coal to be loaded by the conveyor into cars "spotted" on the track by a small winch without the usual transportation delays incident to normal loading practices. The company using this system believes that production can be increased appreciably, and contracts for making and testing the needed equipment were placed with manufacturers.

The traditional method of mining thick, steeply pitching anthracite beds by driving breasts straight up the pitch and back slicing fails to lend itself to increased output, (1) because only one cut per shift can be taken from the breasts and (2) because the usual recovery of pillar coal seldom exceeds 40 percent of the total coal left in the pillars. The first weakness was attacked by driving slant chutes in the bed at an angle of 30° with the horizontal and by cutting the coal mechanically. This 30° angle provides a less hazardous and more easily traveled floor on which the miner will work than the steeper angles, often as great as 85°. Moreover, the fact that the coal is cut requires less time for its removal and leaves more solid coal faces, thus increasing safety. The second weakness - the low extraction of pillar coal - was attacked by working the back ends of the pillars in a line advancing along the strike of the bed and by following this robbing line with backfill to support the walls and minimize rock falls. The largest anthracite reserves are found in thin, steeply pitching beds. Mechanical mining of this coal to increase production is being studied.

Realization of above-discussed objectives of mechanized mining will allow operators to produce anthracite more cheaply without reducing wages and thus enable them to be in a more advantageous position to market their product

20/ Forbes, J. J., and Weaver, H. J., Blasting Hazards in Strip Mines Adjacent to Underground Workings: Bureau of Mines Inf. Circ. 7296, 1944, 5 pp.



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competitively. These improved practices will strengthen the economy of the anthracite industry and increse the living standards of the entire anthracite region.

Flood Prevention in Anthracite Mines

The flooding of active anthracite mines in certain areas of Pennsylvania is a constant menace to life and property, threatening to curtail the life of the anthracite industry and to decrease the present production of anthracite. This encroachment of mine water comes directly from the surface or from infiltration through inadequate barriers between active and abandoned mine workings. To obtain factual information on the many complexities of the anthracite mine-flood problem that will aid in minimizing the threat and disastrous consequences of a sudden inrush of water from nearby surface streams or from adjacent flooded abandoned mines, the Bureau of Mines conducted inquiries, made scientific and technologic investigations, and participated in the construction of mine flood-prevention projects. Recommendations on the projects completed were given to industry.

Permissibility Schedule for Diesel Mine Locomotives

Information obtained in studies of the hazards of operating Diesel engines in confined spaces was used in preparing a permissibility schedule for Diesel mine locomotives.21/ This schedule gives detailed information on the requirements that must be met by a permissible Diesel mine locomotive. A locomotive designed to meet these requirements can be submitted to the Bureau of Mines for tests, and if it meets all requirements and passes all tests it will be approved for underground use in coal mines or other confined spaces. Development of such locomotives has been retarded by the war because the facilities of locomotive and engine manufacturers were utilized full time in producing equipment for the armed forces. Nevertheless, interest in this development has continued as indicated by numerous requests for information from these manufacturers and from mining engineers. It is believed, therefore, that the development of permissible Diesel mine locomotives will proceed rapidly when the necessary production facilities become available.

Effect of Pressure on Exhaust Gases from Diesel Engines

Studies were completed on the effect of barometric pressure on the composition of exhaust gases from Diesel engines. Test conditions and results with one engine (engine B) were reported.22/ Similar tests were made during the fiscal year 1945 on two other engines (A and C). The results of these tests agreed with the previous data, which showed that the production of toxic exhaust gases at a given fuel:air ratio was not affected significantly by

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21/ Bureau of Mines, Procedure for Testing Diesel Mine Locomotive for Permissibility and Recommendations on the Use of Diesel Locomotives Underground: Sched. 22, approved September 2, 1944, 31 pp.

22/ Huff, W. J., Studies of Explosives and Explosions Fiscal Year 1944: Bureau of Mines Rept. of Investigations 3794, 1945, 35 pp., esp. pp. 20-21.



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barometric pressure. However, it must be remembered that reduction in barometric pressure increases the fuel:air ratio at a given throttle setting or at a given rate of fuel consumption. Since, at the higher fuel:air ratios, the concentration of carbon monoxide increases markedly as the fuel:air ratio increases, it is necessary to limit the maximum quantity of fuel supplied to the engine to prevent production of dangerous quantitites of carbon monoxide at the lower barometric pressures.

The engine in a permissible Diesel mine locomotive will be equipped with a flame protective device and air cleaner in the intake system and with a flame protective device and exhaust-gas cooler in the exhaust system. Consequently, when the engine is operating there will be a pressure drop across any unit that offers resistance to flow of gas through it. If this pressure drop is excessive, combustion in the engine may be affected adversely, and production of toxic gases may increase. Studies were made with engines A and C of the effect on exhaust-gas composition (1) of reduced pressure in the intake system when the pressure in the exhaust system was held constant and (2) of back pressure in the exhaust system when the pressure in the intake system was held constant. Variations of concentration of carbon monoxide with fuel: air ratio at different reduced pressures and with fuel consumption were determined. The results showed that hazardous increases in carbon monoxide may occur from restrictions in the systems and attendant reduced absolute pressures in the intake manifold or excessive increased absolute pressures in the exhaust manifold. Removal and cleaning of the protective devices in the intake and exhaust systems to keep the engine in proper condition were recommended.

Relationship of Safety and Efficiency in Coal Mining

Accident records have an important bearing on the determination of the most effective methods for preventing accidents at coal mines and, hence, on the cost and rate of production. Analysis and interpretation of statistical data reveal the prevalent types of accidents and their causes, either on a national or local basis, and provide information necessary for accident-prevention work.[23/] Data are given for the number of accidents from different causes in bituminous-coal mines, and trends of frequency or severity rates are discussed.

Roof Control

The greatest number of accidents from any cause in the bituminous-coal mines of the United States occur from falls of roof and coal; about half of all the fatalities and more than one-fourth of all the nonfatal injuries result from this cause. Control of mine roof has been a major study of the Bureau of Mines since its inception, and the information obtained established that many of these injuries are avoidable, if proper precautionary measures

23/ Bureau of Mines, Accident Statistics as an Aid to Prevention of Accidents in Bituminous-Coal Mines. Coal-Mine Accident-Prevention Course - Section 1: Miners' Circ. 47, 1945, 40 pp.



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are taken. About four-fifths of these accidents result from some human failure.24/ Physical factors that affect falls of roof and coal are pointed out, and methods of overcoming or controlling these conditions are described. Safety instructions and supervision are treated as essentials, in addition to the proper methods of supporting mine roof. Methods of roof testing with recommended implements for testing and methods of mining and other underground activities affecting roof control are described.

Haulage Accidents

Accident records compiled by the Bureau show that about one-fifth of all lost-time injuries, fatal and nonfatal, are the result of accidents in transportation; they are exceeded only by accidents from falls of roof and coal. The upward trend of the number of injuries from haulage indicates that the increased application of mechanical loading devices and the speed-up in haulage to maintain production have not been accompanied, in many instances, by necessary improvements in haulage installations and maintenance. Haulage accidents are serious from the standpoint of safety and are costly economically. Haulage equipment everywhere in the mine should be handled solely by experienced haulage employees.25/ Various types of equipment with their unsafe aspects are discussed and methods for correction are suggested. Recommendations are included for the avoidance of human, mechanical, and physical failures in connection with bituminous-coal mine haulage.

Coal-Mine Hoisting

A uniform hoisting-signal code for coal and other mines that hoist from only one level has not been adopted by the coal-mining industry, and only a few States have promulgated adequate laws or regulations governing hoisting-signal codes. Accidents to men and property have been caused by confusion in meaning of signals used by men moving from one mine to another. Reliable mechanical and electrical signaling devices have been developed, and some attention has been given to the formation of safety rules. A uniform hoisting-signal code is suggested that might be adopted by the various coal-mining States and the coal-mining industry.26/

Mining laws of coal-producing States differ widely with respect to safety catches on mine cages, and requirements for testing are generally indefinite in scope. To determine the effectiveness of safety catches, tests should be made under conditions similar to those existing when men are being handled.27/

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24/ Bureau of Mines, Prevention of Accidents from Falls of Roof and Coal. Coal-Mine Accidident-Prevention Course - Section 2: Miners' Circ. 48, 1945, 114 pp.

25/ Bureau of Mines, Prevention of Haulage Accidents. Coal-Mine Accident-Prevention Course - Section 3.: Miners' Circ. 49, 1946, 58 pp.

26/ Harrington, D., and East, J. H., Jr., Suggested Hoisting-Signal Code for Slope Coal Mines and for Shaft Mines Having Only One Level: Bureau of Mines Inf. Circ. 7291, 1944, 9 pp.

27/ Sloman, H. J., Testing Safety Catches on Mine Cages at Some Eastern Bituminous Coal Mines: Bureau of Mines Inf. Circ. 7290, 1944, 20 pp.



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Recommended methods of testing are described and their relative effectiveness is discussed.

## Inspection Standards for Bituminous-Coal and Lignite Mines

To assist Federal coal-mine inspectors in their duties and to provide concise information to those in industry who are concerned with coal-mine safety, the numerous safety recommendations made by the Bureau of Mines relating to tentative bituminous- and lignite-mine inspection standards were summarized in one publication.28/ Numerous excerpts are included from Federal, State, and private publications relating to meritorious mining laws of several States, and to the experiences and writings of Bureau engineers, of other agencies, and of individuals. An extensive bibliography is given to enable Federal inspectors and other interested readers to find more detailed information on particular subjects.

The latest revision of inspection standards or recommendations for use in Federal inspection of bituminous-coal and lignite mines has been compiled.29/ These standards incorporate important alterations and additions made since 1943 (Information Circular 7268) because of changes in mining practices and temporary shortages of some safety equipment; several previous standards were found not generally applicable and have accordingly been deleted.

## Inspection Standards for Anthracite Mines

Federal inspection of coal mines by the Coal Mine Inspection Division has required formulation of specific safety standards for the guidance of inspectors in making proper recommendations to correlate unsafe practices. Because the methods, practices, and conditions in anthracite mines differ greatly from those in bituminous mines, a different set of standards, based on practices that have been found safest and most practical by underground test and technical research, was prepared.30/ Each standard is explained, where the reason for it is not entirely obvious, and numerous excerpts from Federal, State, and private publications are included. The writings and experiences of authorities in the Bureau of Mines and other agencies are quoted for pertinent reference.

## Coal-Mine Explosions and Fires During the Fiscal Year 1944

Although the explosion fatality record showed a considerable improvement over the preceding four fiscal years, 94 deaths resulting from 23 coal-mine explosions were reported for the fiscal year 1944.31/ Notwithstanding a long

28/ Bureau of Mines, Explanation and Justification of Tentative Inspection Standards for Bituminous-Coal Mines and Lignite Mines: Miners' Circ. 45, 1944, 139 pp.

29/ Bureau of Mines, Inspection Standards for Bituminous-Coal and Lignite Mines, Revised July 1945: Inf. Circ. 7333, 1945, 57 pp.

30/ Bureau of Mines, Explanation of Tentative Inspection Standards for Anthracite Mines: Miners' Circ. 46, 1945, 118 pp.

31/ Harrington, D., and Fene, W. J., Coal-Mine Explosions and Coal and Metal-Mine Fires in the United States During the Fiscal Year Ended June 30, 1944: Bureau of Mines Inf. Circ. 7330, 1945, 35 pp.



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history of explosions and fires resulting from them, continued use of hazardous procedures in coal mines is revealed by the reports. An epidemic of disastrous mine fires of electrical origin during 1943 and 1944 emphasized the need of improved methods of protecting underground electrical circuits. Committees of mining-electrical engineers, electric manufacturers' representatives, and others are cooperating with the Bureau of Mines in seeking means to solve this problem.

Electrical Hazards of Fires and Explosions

In connection with the prevention of mine fires and explosions and with rescue and recovery work following coal-mine disasters, such as occurred in 1943 and 1944, special investigations were conducted by the Electrical-Mechanical Section of the Safety Division as follows: (1) Experiments to devise a means of communication with men trapped in a mine; (2) tests of flame-resisting qualities of trailing cables used with portable equipment in mines; (3) experiments to determine cause of explosions in enclosures for electric parts on approved machines in mines; and (4) tests of gas-ignition hazard connected with automatic controls for mine pumps. In 1943 and 1944 more than 40 serious fires occurred in the coal mines of the United States, and over 100 lives were lost in fires of electrical origin chargeable to the trolley-haulage system. Bare trolley wires and the entire trolley-haulage system are outstanding sources of electric arcs and sparks; but this equipment, which is efficient, even though hazardous, cannot be discarded at once and replaced by other equipment. Available equipment, therefore, must be carefully installed and maintained, and safely operated to minimize losses of life and property.32/ Other modes of transportation that will allow bare trolley wires to be eliminated are discussed, and suggestions are given for minimizing the hazards of arcs and sparks from trolley-wire systems. The ultimate solution of the basic problem is not immediately obvious and the cooperation of the industry and the Bureau of Mines must be continued to that end.

Fuel for Flame-Safety Lamps

Satisfactory operation of a flame-safety lamp depends upon the kind of fuel used as well as the design and the assembly of the lamp. Trouble experienced in operating permissible flame-safety lamps at mines is due to the common use as fuel of motor gasolines, none of which are suitable in these lamps.33/ Recommended fuels are listed with information as to where they may be procured.

Procedure for Investigating Explosion-Proof Mine Equipment

The arrangements and specifications under which tests are made for Bureau approval of electrical equipment used in gassy mines are modified from

32/ Griffith, F. E., Gleim, E. J., Artz, R. T., and Harrington, D., Prevention of Fires Caused by Electric Arcs and Sparks from Trolley Wires: Bureau of Mines Inf. Circ. 7302, 1944, 10 pp.

33/ Hooker, A. B., and Coggeshall, E. J., Fuel for Permissible Flame Safety Lamps (A Revision of Investigations 3389, 1938, 5 pp.): Bureau of Mines Inf. Circ. 7301, 1945, 6 pp.



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year to year as new equipment and new standards are evolved. A revised schedule for testing and approving permissible electric equipment was published.34/

Permissible Mine Equipment

The Bureau continued to investigate electrical equipment used in mines in connection with the prevention of explosions and fires. A list of permissible mine equipment tested and approved under Schedule 2D during the calendar year 1944 was published.35/

Hazards of Auxiliary Fans in Coal Mines

The auxiliary fan as commonly used is intermittently operated and as frequently installed causes recirculation of mine atmosphere, which results in the accumulation of methane that may be ignited by an electric spark or other means. Use of electrically driven auxiliary blowers has resulted in a number of explosion disasters. The experience and observations of field safety Bureau engineers condemn the use of this system in coal mines. Proponents of the system outside the Bureau believe that such blower fans can be safely used if certain regulations and restrictions are imposed, but satisfactory rules have not yet been proposed. Reports of inspected coal mines in which blower fans are employed show that 95 percent were operated by electricity and that in a majority of these cases definite hazards existed.36/ The circumstances of a number of coal-mine explosions where blower fans were a contributory factor are reviewed, and the conclusion is drawn that general use of such fans is not justified.

Design of Ventilation Air-Injectors

The injector system of tunnel ventilation usually realizes only a little more than half the efficiency obtainable with a correct relation of jet size to tunnel area. Methods of designing injectors and predicting their performance under low-pressure air-flow conditions were developed, based on the constant-momentum theory of Prof. W. S. Weeks and confirmed by experiments in low-pressure-jet designs.37/ With high-pressure-jet designs, agreement of the formulas presented in the paper with experiments is approximate but sufficient for purposes of design. Formulas are presented for facilitating the design of compressed air-operated injectors, and a Venturi design is proposed for general utility in mines for auxiliary injector-pipe ventilation.

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34/ Bureau of Mines, Procedure for Testing Junction Boxes and Electric Motor-Driven Mine Equipment for Permissibility: Sched. 2E, approved February 15, 1945, 19 pp.; Federal Register, vol. 10, No. 41, Feb. 27, 1945, pp. 2239-2240. (Typographic errors in the Federal Register were corrected in Sched. 2E.)

35/ Hooker, A. B., Permissible Mine Equipment Approved During 1944: Bureau of Mines Inf. Circ. 7316, 1945, 4 pp.

36/ Harrington, D., and Warncke, R. G., Some of the Hazards of Auxiliary Fans in Coal Mines: Bureau of Mines Inf. Circ. 7298, 1944, 27 pp.

37/ McElroy, G. E., Design of Injectors for Low-Pressure Air Flow: Bureau of Mines Tech. Paper 678, 1945, 50 pp.



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Injectors can be designed for high efficiency or for high ratio of total air flow to jet air flow but not for both, as a reciprocal relation exists between efficiency and quantity.

Application of air jets to mine ventilation is surveyed in another publication.[28] Examples of applications of injector methods to ventilation problems in other industries are described, and new applications can be expected to evolve from the information presented. A method is proposed for using easily constructed injectors to regulate split air flow in coal mines in a way that conserves some of the energy now lost at regulators. The pressure change in a diverging discharge to atmosphere offers a means of securing pressure and exhaust in close juxtaposition.

Coal-Mine Health Hazards

Laboratory and field investigations of health conditions in anthracite and bituminous-coal mines were carried out in connection with requirements of the Federal Coal Mine Inspection Act. Dust and gas samples were collected and analyzed. Plans were made for the development and study of a wet-type auger drill for use in bituminous mines. Substitution of a quartz-free or low-quartz material for the high-quartz sand used under the wheels of mine locomotives is probably the best method of controlling this silicosis hazard. Dust from sand used for this purpose is disseminated into the air by handling during unloading, drying, transporting, sprinkling on the rails, passage of trains over the tracks where sand has been used, or walking over deposits of sand on haulageways.[39] Medical examinations of miners and tests of sand being used establish a definite connection of this material and the contraction of silicosis.

A filter-paper method[40] was developed for obtaining dust-concentration results comparable to those obtained by the widely used impinger method. The new method consists of the removal of dust from air by drawing the air, with a hand-operated pump, through special filter paper; removal of the dust from the paper by simple shaking in a dust-free liquid; and counting the dust by the same procedure used for impinger samples. Lintless, high-wet-strength, hardened filter paper is used. Light-transmission determinations may be made on the paper before and after sampling to obtain an estimate of dust concentration at the time of sampling. Comparative determinations on silica dust in the air of a test chamber and on coal dust in the air of a coal-sampling room showed that the results of regular light-field counts on the filter-paper samples agreed with the average of the results of two simultaneous midget-impinger samples, each collected within 5 cm. distance of the filter-paper

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38/ McElroy, G. E., The Role of Air Jets in Mine Ventilation: Am. Inst. Min. and Met. Eng. Tech. Pub. 1912, July 1945, 16 pp.

39/ Brown, C. E., and Schrenk, H. H., Control of Silicosis Hazard by Substitution of Quartz-Free or Low-Quartz Material for Sand Used Under Mine Locomotives: Bureau of Mines Inf. Circ. 7297, 1944, 5 pp.

40/ Brown, C. E., Filter-Paper Method for Obtaining Dust-Concentration Results Comparable to Impinger Results: Bureau of Mines Rept. of Investigations 3788, 1944, 20 pp.



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sample. Results of dark-field counts on the filter-paper samples were up to two times higher than those on the corresponding impinger samples, indicating a higher efficiency by the filter-paper method for collecting finer particles. The filter-paper sampler is simpler, cheaper, more rugged, and more convenient to use than the midget impinger. It may be used, if desired, for collecting samples of other unhygienic particulate matter than pneumoconiosis-producing dusts and should facilitate industrial hygiene activities, particularly efforts on the control of pneumoconiosis.

## Use of Explosives and Gaseous Explosions

### Increase in Charge Limit of Permissible Explosives

As one means of increasing coal production, the coal-mining industry in 1943 requested that the Bureau of Mines consider the use of permissible explosives in charges greater than the then permissible limit of 1.5 pounds. Since then, a continuing study has been conducted in the Experimental coal mine by the Experimental Coal Mine Section, with the advice and collaboration of the Explosives and Coal Mine Inspection Divisions, to determine factors affecting the ignition of gas and dust in a coal mine using higher weights of explosives. Preliminary studies have established tentatively safe conditions under which permissible explosives may be used in quantities up to 3 pounds per shot. These conditions are incorporated in the latest permissibility schedule.41/ This schedule is a revision of Schedule 1E, approved June 15, 1944, and sets forth the conditions under which a 3-pound charge of explosive can be used in coal mines. Tests required for approval of a sheathed explosive are described. Under Schedule 1F stemming is no longer required for use with a blasting device. For charges over 1.5 pounds certain additional safety precautions as to depth of hole, method of charging the explosive, testing for gas before and after firing a shot, and limits on toxic gas emission, must be observed.

The investigation was continued during this fiscal year, and 224 additional tests were made in the Experimental mine. The chief objective was to establish the limiting conditions under which a highly-inflammable gas mixture (8 to 9 percent methane - air) near the coal face will or will not be ignited by the flame or products of detonation from the explosive. A high-rate gelatin-type permissible explosive was used in most of the tests. This explosive was chosen because, under severe experimental conditions, ignitions of surrounding inflammable gas-air mixtures were obtained and therefore it was possible to determine the additional precautions necessary to prevent such ignition. The explosive cartridges used were 1.25 inches in diameter and 8 inches long, and each weighed about 0.47 pound. The explosive in all instances was loaded to the rear of the borehole, and was fired by a No. 6 detonator at the rear of the charge. In "file loading" the cartridges were placed in the

41/ Bureau of Mines, Procedure for Testing Explosives (Including Sheathed Explosives) and Blasting Devices for Permissibility and Suitability: Sched. 1F, Approved January 20 and March 14, 1945, 15 pp.; Duplicated from Federal Register, vol. 10, No. 26, Feb. 6, 1945, pp. 1476-1483; No. 60, Mar. 24, 1945, p. 3131.



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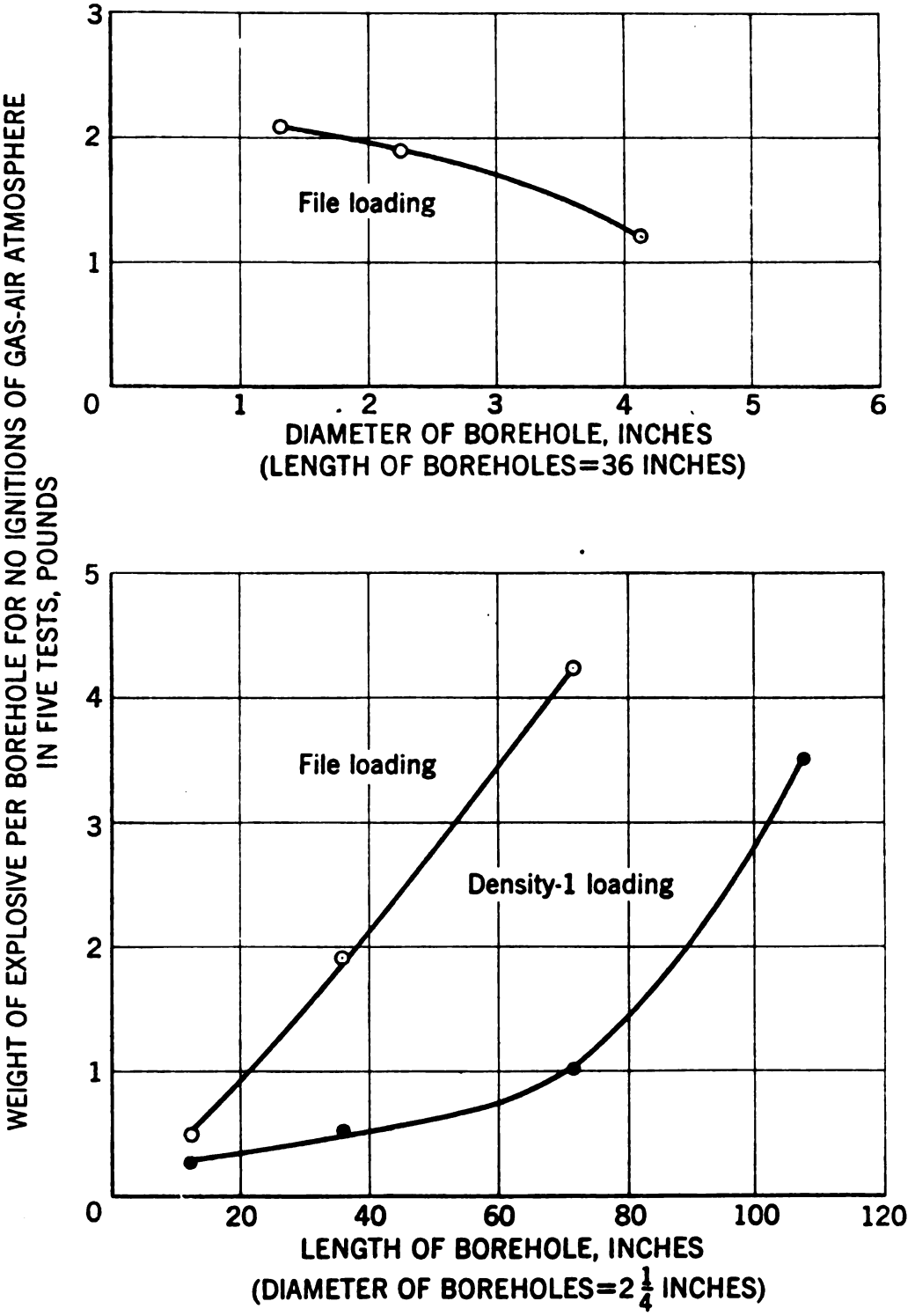
WEIGHT OF EXPLOSIVE PER BOREHOLE FOR NO IGNITIONS OF GAS-AIR ATMOSPHERE IN FIVE TESTS, POUNDS
File loading
DIAMETER OF BOREHOLE, INCHES
(LENGTH OF BOREHOLES=36 INCHES)
File loading
Density-1 loading
LENGTH OF BOREHOLE, INCHES
(DIAMETER OF BOREHOLES=2 1/4 INCHES)

Figure 9. - Relation of dimensions of unstemmed boreholes to limiting charge of gelatin-type permissible explosive to prevent ignition of gas at coal face.

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borehole end to end without being deformed; in "density 1" loading they were deformed to fill the cross section of the borehole without changing appreciably the density of the explosive. Tests were made under four sets of conditions: (1) Blow-outs, in which flame and products of the explosive are ejected mainly parallel with the axis of the borehole in solid coal; (2) blow-throughs, in which the products are ejected through the rupture of a weak sidewall of a borehole in solid coal, either to an adjacent undercut or to a shear; (3) fissures, in which the products are ejected largely through fissures in the coal or through openings simulating fissures; and (4) suspended charges, in which the explosive is not confined by coal, but is fired directly within a gas zone. Five successive tests were made under each set of conditions.

Figure 9 shows the relation for blow-out tests without stemming between the dimension of the unstemmed borehole and the maximum allowable weight of a gelatin-type permissible explosive to prevent ignition of gas at the coal face (based on five trials). In general, shots with file-loaded charges are less likely to ignite gas at the face than charges of the same weight packed into the boreholes (loading density 1). Preliminary tests with unstemmed charges also showed that an inflammable gas mixture in the borehole, intentionally introduced in some tests, has no significant effect on the probability of gas ignition at the coal face.

In the blow-through tests, all made with stemming in 2.25-inch-diameter boreholes, no ignitions were obtained with any quantity of explosive up to 8 pounds, the highest tried, with thickness of wall of the borehole as low as 3 inches. These results applied to both under-cut and shear-cut faces. An earlier test gave ignition with a.6-inch wall, but this may have been caused by a fissure in the wall.

Preliminary tests with artificial fissures, in the form of circular holes introduced between the shear cut and the borehole, indicate that such openings constitute a definite hazard when explosives are fired in the presence of gas at the coal face, regardless of the amount of stemming in the borehole. Ignitions of gas resulted, with a fissure of 2.25-inch diameter through an intervening wall of coal 18 inches long and with a fissure of 1.25-inch diameter through 6 inches of coal.

In tests with charges of explosives suspended in the center of a gas-filled zone, ignitions of the gas resulted with as little as 0.09 pound of explosive. Accidental firing of explosives under such conditions presents a very grave gas-ignition hazard in a coal mine.

## Gallery Tests of Permissible Explosives

In connection with the studies in the Experimental mine it has been necessary to make gallery tests for correlation purposes and to provide more satisfactory answers to certain specific questions than could be obtained by mine tests. Gallery tests were made to determine the effects of (a) type of stemming, (b) condition of borehole, (c) length of borehole, (d) method of loading the charge in the test cannon, and (e) weight of charge for weights



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of explosives so small that the detonator has an appreciable effect on the ignition probability of 8-percent natural gas-air mixtures. Preliminary tests indicated that the type of stemming has a marked effect on ignition probability. Results, based on 10 trials each, for a 200-gram charge of high-rate gelatin permissive explosive with single file loading, back initiation, and stemmed with various materials, showed that the more loosely packed, coarser particle size stemmings seem to be more effective in reducing ignition probability. Shots fired from a borehole expanded by previous shot firings at the position of the charge indicated very definitely that ignition is less likely than from shots fired from new undeformed boreholes. Results of tests to determine the effect of the length of the borehole showed that only slightly greater ignition probability is indicated for a 12-inch than for a 21.5-inch borehole. To investigate the effect of method of loading a technique of alternate shooting was adopted because of the marked effect of borehole condition. The tests were made in groups of five shots, and the order of shooting is indicated in the last column of table 5. After the tenth group of shots the borehole had started to expand markedly, and the ignition probabilities thereafter are probably too low. The results are far from complete but indicate that the density-of-1 loading presents an increased ignition hazard for this high-rate gelatin-type permissible explosive and are in contradiction to results previously obtained with two low-rate explosives, for which the air-spaced shots gave greater ignition probabilities.

TABLE 5. - Effect of method of loading explosive on ignition of 8-percent natural gas-air mixtures in gallery. Explosive D-7383, 200 grams.

| Method of Loading | Weight of stemming, gm. | Probability of ignition | Order of tests (group of 5 shots) | |
|---|---|---|---|---|
| Single file, Back-initiated, Asbestos disk, Fire-clay stemming. | 200 | 0.2 | (1) | (4) |
| | 225 | .1 | (9) | (12) |
| | 250 | .0 | (15) | (17) |
| Density-of-1, Back-initiated, Air space of 4-7/8 inch, Asbestos disk, Fire-clay stemming. | 200 | .2 | (2) | (5) |
| | 225 | .0 | (10) | (13) |
| Density-of-1, Back-initiated, Asbestos disk, Fire-clay stemming. | 200 | .5 | (3) | (6) |
| | 275 | .0 | (11) | (14) |
| | 250 (7 shots) | .0 | (16) | |
| Single file, Back-initiated, Asbestos disk, Fire-clay stemming, Wire placed over charge. 1/ | 200 | .1 | (7) | (8) |

1/ To determine whether wire in the spacer might introduce an appreciable effect, these shots were made with a weight of wire equivalent to that of a spacer placed over the charge.



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Tests of the dependence of ignition probability on weight of charge for a low-rate gelatin-type permissible explosive presented a very anomalous behavior. Accurate distribution curves are being obtained for both high-rate and low-rate permissibles, gelatin and nongelatin types, to determine whether the above noted behavior is noticeable for other types of permissible explosives. The explosives selected represent the four common types of permissibles: Explosive A - high-rate gelatin-type explosive; explosive B - low-rate gelatin-type explosive; explosive C - high-rate nongelatin-type explosive; and explosive D - low-rate nongelatin-type explosive. Distribution curves for A, B, and C have been completed and definitely indicate that the ignition probability first decreases then increases as the charge weight is increased. To determine whether the ignitions at the lower charge weights may be due to burning detonator fragments, distribution curves were also obtained using Special No. 6 electric blasting caps with essentially the same explosive ingredients as the Standard No. 6 blasting cap, but with the combustible materials in the electric blasting cap plug replaced by a noninflammable glass tape. In all instances, the results indicate that the anomalously high ignition probabilities at the lower charge weights are probably due, at least partly, to burning of the combustible materials in the electric blasting-cap plug. However, since the anomalous trend of the distribution curve is shown for both types of detonators, the presence of combustible material in the detonator plug does not entirely account for such a trend. One possible explanation might be that, due either to the geometry of placement of the detonator or because it is not strong enough to detonate the explosive completely, burning fragments of explosive are thrown into the gallery atmosphere and ignite the gas-air mixture.

Demonstrations of Safety of Explosives

Conducted tours of the Explosives Testing Station at Bruceton, Pa., were made for individuals, among them representatives of the Government of Brazil and of the Government Purchasing Commission of the Soviet Union. Demonstrations were made to illustrate the safety of permissible explosives when used properly and the danger of using black blasting powder because of the ease with which it will ignite bituminous-coal dust when fired into it.

Routine and Special Tests on Explosives

In all, 4,746 routine tests of various kinds were made under the Bureau of Mines schedule and for various investigations during the fiscal year.

Special tests were made for manufacturers of permissible explosives upon request and for general information. These tests included: Approval in size of six permissible explosives not previously approved for particular brands; determination of gaseous products on six samples of 40-percent ammonia-gelatin dynamites of various compositions; determination of rate of detonation in paper tubes of five samples of dynamite; and ballistic pendulum tests and a limit-charge test with the explosive suspended in the gallery on five samples of explosives.



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The explosives chemical laboratory analyzed 419 samples during the fiscal year. This work included chemical analyses of explosives, blasting supplies, and detonators, and examination of enemy munitions.

## Consumption of Permissible Explosives

A permissible explosive is one that is similar in all respects to a basic sample of the explosive that has passed certain required approval tests of the Bureau of Mines. In blasting coal permissible explosives should be used exclusively; otherwise disastrous explosions may occur. The consumption of permissible explosives for blasting coal during the fiscal year 1945 approximated 97,300,000 pounds. In addition, for the same purpose, approximately 37,500,000 pounds of black blasting powder were used. However, the use of this extremely dangerous explosive has declined rapidly since 1939, when about 48,000,000 pounds of black blasting powder were used as compared with only about 44,000,000 pounds of permissible explosives. In addition to the quantities of permissible explosives and black blasting powder consumed during the fiscal year 1945, there were also used approximately 81,700,000 pounds of high explosives other than permissibles. The total quantities of all explosives used in coal mines totaled 216,500,000 pounds, which is about 49 percent of the explosives used in industry for all purposes.

## Lists of Permissible Explosives

After an explosive or blasting device has passed all the required tests it may be placed on the permissible list. This list is constantly being revised due to additions of explosives and blasting devices which have passed the tests and to transfers between the active and inactive lists. As of June 30, 1945, the active lists contained the names of 178 explosives and 9 blasting devices. This represents an increase of 4 explosives over the list for the previous fiscal year. Six explosives were submitted for tests, 5 passed the required tests, and 1 failed to pass. Two were transferred from the active to the inactive list, and 1 was placed on the active list as an additional name for an explosive already on the list. One sample was also submitted for complete tests to establish new basic data. The same 9 models of Cardox remain on the list; the safety of these devices with a heater element with a change in its composition was established by new tests. A new type of match assembly for igniting the Cardox heater element was submitted and approved.

## Gallery Tests of Sheathed Explosives

Fifteen brands of permissible explosives with sheaths of various compositions were tested in the gallery. Most of these were in cartridges 1.25 inches in diameter; a few were 1.5 inches in diameter. Except for the gelatin-type permissible explosives and one of the granular type, all samples passed the suspended test with a differential of at least 100 grams between the sheathed and unsheathed cartridges. One permissible semigelatin-type explosive passed the test when the cartridge diameter was 1.25 inches but failed when it was 1.50 inches. For the larger-diameter cartridge the weight of sheathing material was less than that for the smaller cartridge; this may be one reason why the larger-diameter cartridge was not as safe as the smaller



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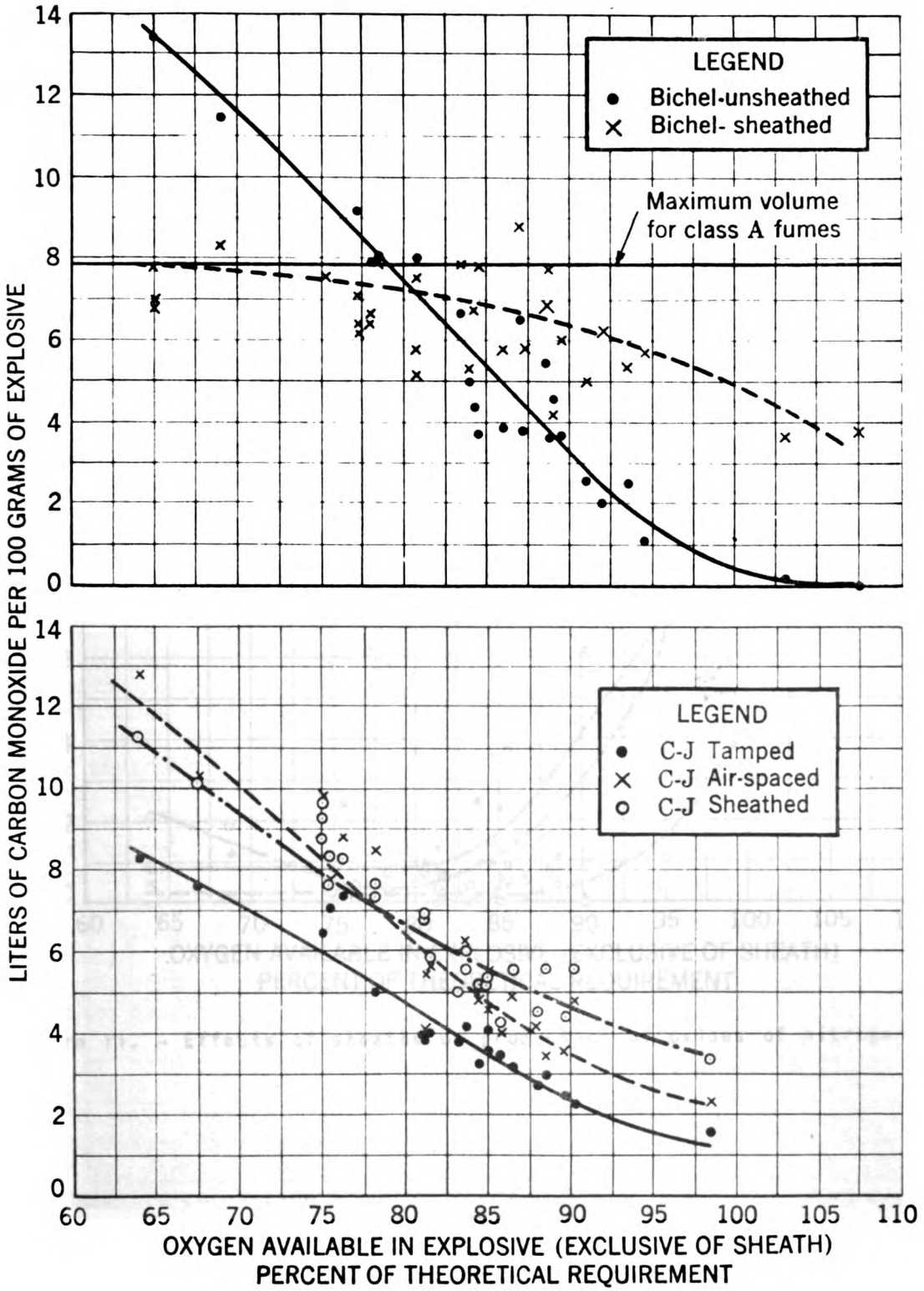


Figure 10. - Effects of sheaths on production of carbon monoxide.

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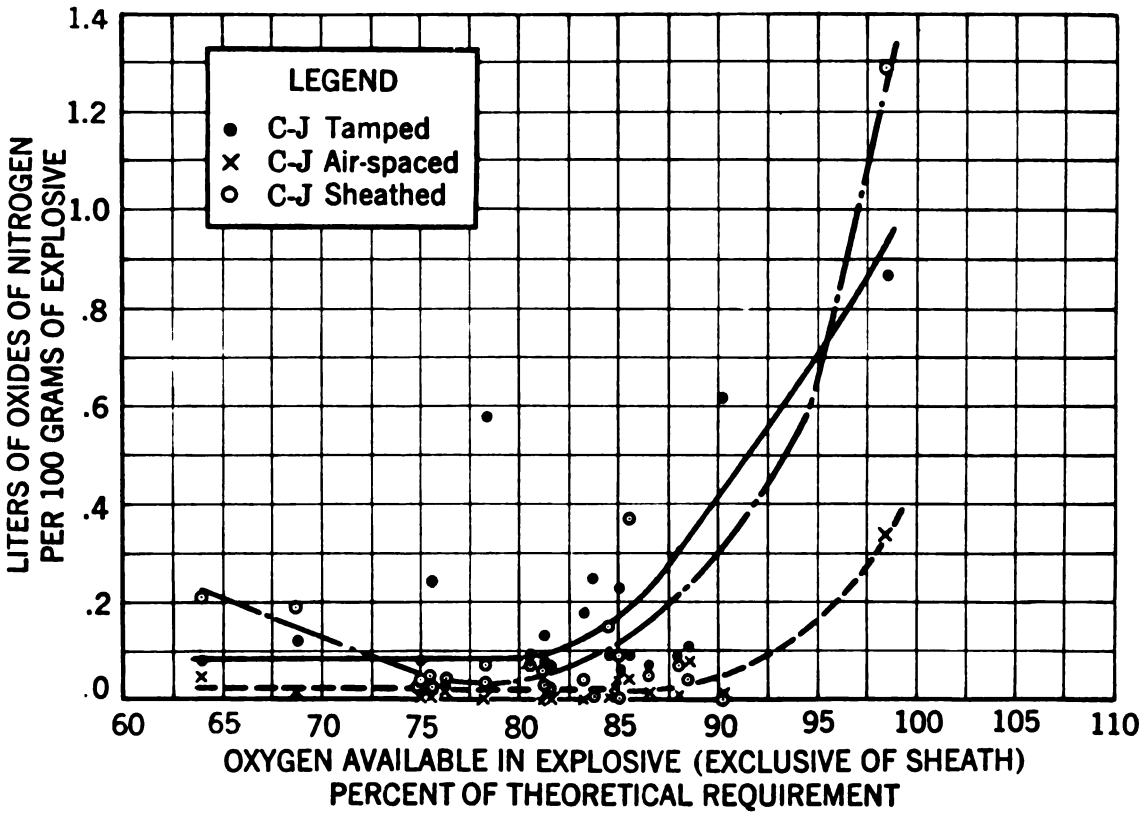


Figure 11. - Effects of sheaths on production of oxides of nitrogen.

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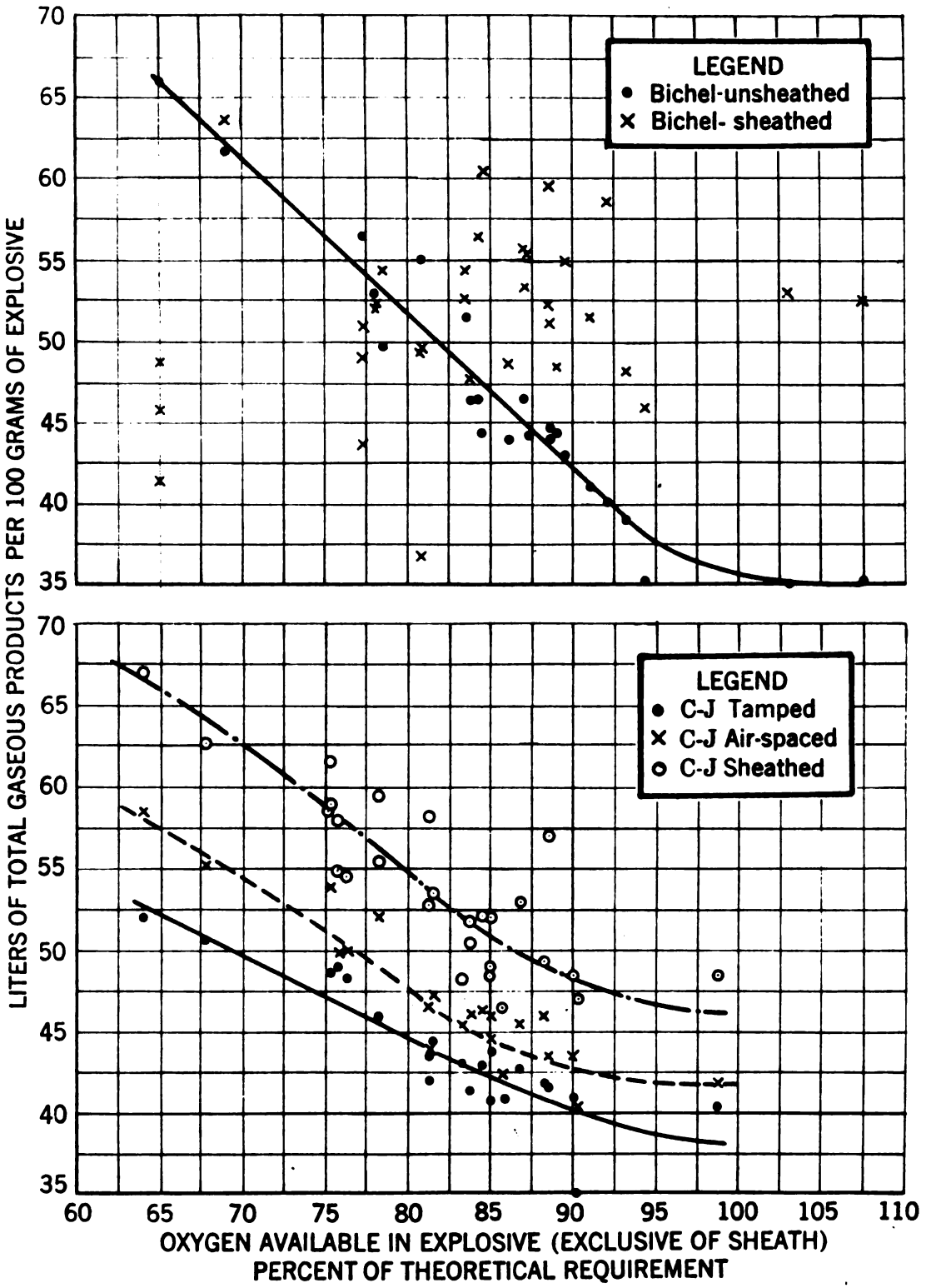


Figure 12. - Effects of sheaths on production of total volume of gaseous products.

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one. All brands when sheathed, passed "gallery test 1" with charges twice that of the respective unit with deflective charge. All brands passes "test 4," although only 5 of the sheathed brands were fired with charges of 3 pounds, exclusive of weight of sheath. Detonation rates were determined for some of the brands; the rate for sheathed cartridges averaged 200 meters per second lower than that for unsheathed cartridges.

Effect of Sheaths on Poisonous Gaseous Products from Permissible Explosives

Recent studies by the Explosives Division and earlier tests by both this division and testing stations abroad indicate that the ignition hazard of explosives fired in the presence of gassy atmospheres may be reduced by the addition of a suitable sheath. However, reduced ignition hazard does not necessarily mean that an explosive is safer, because poisonous gases are produced in the detonation of explosives and may present an important hazard if present in sufficient quantities.

The quantity of poisonous gases produced by permissible explosives shot in the Bichel gage based on 1.5 pounds of explosive determines the fume classification into which explosives are placed:42/ Class A, not more than 53 liters; class B, more than 53 but less than 106 liters; and class C, more than 106 but less than 158 liters. An explosive is not permissible if more than 158 liters of poisonous gases are produced from 1.5 pounds of explosive or if more than 5 liters of oxides of nitrogen are produced from 1.5 pounds of explosive when sheathed. Since the oxygen balance of the explosive, the nature of the material in contact with the explosive, and other factors are known to affect the gaseous products from explosives, it was of interest to determine how gaseous products are affected by sheaths composed of flame-extinctive materials and sometimes containing carbonaceous combustible material in addition to the sheath wrapper. Two types of apparatus were employed in the determination of the gaseous products: In the Bichel gage, gases are produced by detonation at low loading densities, without stemming; the Crawshaw-Jones (C-J) apparatus permits tamping and use of stemming, affording a higher degree of confinement. Fifteen permissible explosives, 6 of which were in two sizes of cartridges, and 8 different sheaths were tested in continuation of the previous study of the effects of sheaths on the gaseous products from explosives. Three of these explosives were of the gelatin type, and 2 were low-density explosives. The rates of detonation ranged from 1,800 to 4,800 meters per second. No. 6 mercury fulminate-potassium chlorate electric detonators with 4-foot leg wires insulated with cotton impregnated with an asphaltic material and paraffin were used in tests in the Crawshaw-Jones apparatus; in Bichel-gage tests the insulation was removed from the leg wires. The oxygen balance of the complete detonator was -8.6 grams and -2.8 grams with the cotton insulation removed. Oxygen requirements, as well as the nitrogen and carbon contents of the detonator, were included in the material balances. Toxic carbon monoxide and even more toxic oxides of nitrogen are normal products of the decomposition of explosives and are of primary importance. Figures 10 and 11 show the effects of sheaths on the production of these gases. As an indication of possible performance properties and extent of decomposition of the sheath, the total gaseous products are important. Figure 12 indicates the effects of sheaths on total gaseous products. In the Bichel gage,

42/ See footnote 41.



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sheaths increased the amount of carbon monoxide when the oxygen available was greater than 80 to 85 percent of the oxygen required for complete combustion; with less oxygen, the sheaths may decrease the quantity of carbon monoxide. Weight ratio of sheath to explosive was important and influenced the production of carbon monoxide. The use of a sheath increased the volume of oxides of nitrogen, but the amounts involved were negligible in Bichel-gage tests, except for low-density explosives which may produce large quantities of this toxic gas when the weight ratio of sheath to explosive is large. This phenomenon also may occur with other explosives, if the weight ratio of sheath is large enough. Total gaseous products were usually increased by the addition of a sheath in the C-J tests but may be decreased in the Bichel-gage tests for oxygen conditions less than 80 to 85 percent of theoretical requirements. Tests in the C-J apparatus were made under three conditions: (1) Cartridges of unsheathed explosive tamped in the borehole and stemmed ("density-of-1"); (2) cartridges of unsheathed explosive laid single-file in the borehole and stemmed; and (3) sheathed cartridges laid single-file in the borehole and stemmed. The results indicate that shots loaded at density-of-1 always produced less carbon monoxide than either air-spaced or sheathed shots. Air-spaced shots produced less carbon monoxide than sheathed shots when the available oxygen exceeded 80 percent of the theoretical requirements for complete combustion. In general, air-spaced shots produced the least amount and a negligible quantity of oxides of nitrogen. Shots loaded at density-of-1 generally produced the largest quantity, and sheathed shots produced intermediate amounts of oxides of nitrogen. When the explosive is nearly balanced or has a positive oxygen balance, large amounts of oxides of nitrogen may be produced from sheathed shots or those loaded at unit density, and significant quantities may be produced from air-spaced shots. The results indicated that sheathed explosives introduce no important hazards in the production of carbon monoxide but may cause undesirable conditions by the increased production of oxides of nitrogen under adverse conditions.

## Sensitivity of Explosives to Initiation by Electrostatic Discharges

Of all hazards associated with explosives, those generally ascribed to static electricity are probably least understood. In 1942 the Explosives Division started an investigation for the Safety and Security Division of Army Ordinance to evaluate certain static electrical hazards associated with the manufacture, storage, and use of explosives. Later, other service and industrial organizations requested the Bureau of Mines to obtain information on static electrical hazards associated with particular problems in the handling of explosives or potentially explosive materials. In connection with these investigations considerable data on static spark sensitivities of explosives have been accumulated. For security reasons, much of this information is restricted at present.

Only a brief summary of the general trends observed from test data that are unrestricted can be presented here. The energy for ignition varies with voltage and overvoltage, but the trend of variation was not the same for all explosives. Large particles ignited less readily than smaller particles, although for some explosives under confinement this effect was not appreciable. Except for primary explosives, the degree of confinement usually had a marked



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effect on ease of ignition and completeness of propagation of the ignition. The ignitions of secondary high explosives unconfined were apparently explosions of fine dust dispersed in the air by the spark, whereas under confinement these explosives detonated. The ignition energies for unconfined samples of finely ground secondary high explosives were invariably less than for the same types of samples under confinement. Metal powders were more sensitive when tested unconfined. Black powder was much more sensitive when tested under confinement. Moist black powder (up to 7 percent moisture) was more sensitive than dry when tested under confinement.

It was of interest to know the electrostatic charge energy that might be built up on the human body. The capacity of the human body depends on many factors, such as body structure and the proximity of other conductors or insulators. If there is contact between the body and some other object of high capacity the over-all capacity will be considerably larger. Some measurements were made of the capacity of several individuals in a building with a grounded-steel framework. When the individual was insulated from the floor by either rubber-soled shoes or a 3/4-inch plate of glass, values of capacity ranging from 0.0001 to 0.0004 microfarad could be obtained. The value of 0.0004 was obtained with the individual leaning over a steel girder while wearing a leather jacket. Some tests also were made in a reinforced-concrete bombproof. Values of 0.00028 to 0.00032 microfarad were consistently obtained when the individual leaned against a wall. For two individuals holding hands the capacity was approximately the sum of their separate capacities. If 0.0003 microfarad is considered a reasonable value of capacity under not too extreme conditions, then an individual charged to 10,000 volts would have a charge energy of $5 \times 0.0003 \times 10^{-7} \times (10,000)^2 = 0.015$ joule. On the basis of present information, it is believed that precautions should be taken to prevent the accumulation of electrostatic charges on individuals around operations involving the handling of explosives that may ignite with electrostatic energies of 0.015 joule or less. It must be emphasized that ungrounded pieces of equipment, wiring, or structures may acquire much larger energies than 0.015 joule and that precautions should always be taken to prevent accumulation of charges on such items around all operations involving explosives.

Effect of Humidity on Sensitivity and Dispersion of Black Powder

Results of studies of the effect of humidity on the sensitivity and dispersion of black powder were published.[43/] This report covers the study of four properties of black powder that might be affected by moisture: (1) Ignition by flame or hot spark; (2) ignition by heat; (3) ignition by friction; and (4) ignition by impact. In addition, the effect of moisture on the dispersibility of black-powder dust was studied to obtain information on its possible influence in the decrease or increase in the incidence of ignition. Humidification of black powder, unless raised to a moisture content where the powder disintegrated, increased the hazard from ignition by flame or hot particle. Fine-grained powders were more readily ignited by flame or hot particles than were coarse-grained powders. When black powder was heated to some

43/ Moore, R. H., and Huff, W. J., Studies of the Effect of Humidity on the Sensitivity and Dispersion of Black Powder: Rept. of Investigations 3782, 1944, 18 pp.



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temperature below its ignition point, an exothermic self-accelerated reaction occurred which ultimately resulted in ignition unless means of removing the generated heat were provided. Depending on outside conditions, this reaction may become important at temperatures near the melting point of sulfur. Small samples and rapid heating did not give satisfactory ignition temperatures by the test method used. Frictional-impact and pressure-friction tests indicated that black powder is relatively insensitive to friction, at least at ordinary temperatures. Impact tests showed that, under moderate confinement, black powder is moderately sensitive to impact. Two percent or more of moisture decreased the sensitivity to impact. Humidification of black powder effectively lowered the dispersibility, except where the deposit had been disturbed or mechanically agitated before being subjected to a blast. Aside from the electrical effects involved, the importance in minimizing accidental ignition of black powder is probably related to decreased sensitivity of moist black powder to impact. Black powder should be kept cool; temperatures should not approach 100° C.

Miniature-Cartridge Test for Detonators

A new test, called the "miniature-cartridge test," was developed for evaluating the relative initiating efficiency or strength of detonators.44/ The test is based on the fundamental and generally accepted concept that the ability of a detonator to initiate an insensitive explosive is the best measure of its initiating efficiency. Various mixtures of TNT and iron oxide of known physical and chemical properties were selected to represent a wide range of insensitive explosives. The experimental technique combined the known advantages of the sand test and the TNT-iron oxide insensitive-powder test. A 5-gram charge of a homogeneous TNT-iron oxide mixture was packed to a constant density (0.94 ± 0.02) in a paper cartridge, 0.5 inch I.D. and 2.75 inches long, and a detonator was inserted to such a depth as to produce maximum initiation. The extent of detonation of the desensitized TNT was measured by firing the miniature cartridge and its detonator in the center of 1,000 grams of rescreened, standard Ottawa sand contained in a steel bomb of 3-inch I.D. and determining the amount of sand crushed. The crushed sand, which passed through a U. S. Standard No. 30 sieve after a prescribed manner of screening, was then weighed to the nearest 0.1 gram and represented the sand pulverized by the TNT-iron oxide and the detonator. From this weight was subtracted the "detonator blank" obtained under similar technique, except that 5 grams of pure iron oxide was substituted for the TNT-iron oxide mixture. The value of sand crushed, thus derived, represented the initiating efficiency of the detonator. Various factors affecting the test were carefully studied. Among the more important findings resulting from investigations with this test were: (1) A priming charge of 80:20 mixture of lead azide and lead stypnate was found to be more efficient than any other priming charge tested; (2) the initiating efficiency of a detonator was improved by substitution of

44/ Grant, R. L., and Tiffany, J. E., Detonators: Initiating Efficiency by the Miniature-Cartridge Test: Bureau of Mines Tech. Paper 677, 1945, 34 pp.; Determining the Initiating Efficiency of Detonators. The Miniature-Cartridge Test: Ind. Eng. Chem., Anal. Ed., vol. 17, 1945, pp. 13-19.



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tetryl, PETN, and hexogen, in the order named, for an 80:20 mixture of mercury fulminate-potassium chlorate; and (3) the test is applicable to both commercial and military detonators and is believed to provide a more accurate quantitative measurement of the initiating characteristics of detonators than any other previously used test. A brief review of other detonator tests for determining the relative initiating efficiency of detonators was given.

## Determination of Explosibility of Potassium Perchlorate and of Mixtures Containing Potassium Perchlorate

In recent years potassium perchlorate has come into extensive use as an oxidizing agent in combustible mixtures. This use was accentuated by the war because of the increased demand for pyrotechnics and the increased use of blasting devices in mining. Certain perchlorate mixtures are used in blasting devices to supply the heat necessary to gasify an inert confined liquid, which, on changing state and increasing in volume, builds up enough pressure within a shell to rupture a strong disk and perform the work ordinarily done by an explosive in the mine. Although these mixtures function to supply heat, they contain all the essentials of explosives, namely, an oxidizing agent with combustibles, which on interaction are capable of releasing a large quantity of heat and gases. Fire hazards associated with the transportation, storage, and use of mixtures containing oxidizing materials and combustibles are generally recognized, but the possible explosion hazard associated with some of the "deflagrating" mixtures is often overlooked. It has been generally assumed by manufacturers that the heater mixtures would merely burn and could not be made to detonate under the most severe conditions. This assumption was based on the fact that they merely burn slowly in the open when ignited by a squib and cannot be detonated in the open, even by a No. 8 detonator.

Potassium perchlorate is a powerful oxidizing agent frequently used as an ingredient of explosive compositions. Under the influence of heat it undergoes decomposition, releasing its oxygen and leaving potassium chloride as a residue. Because it may thus decompose in the absence of a reducing agent, the Bureau of Mines is frequently asked about its explosibility per se and has made a number of tests to obtain this information. Because the data are not complete for all of the work, only general conclusions indicated by test results on three samples will be given. Table 6 shows the composition of the samples tested.

TABLE 6. - Composition of samples

| Sample No. | $H_2O$, percent | $KClO_4$, percent | $KClO_3$, percent | KCl, percent | Charcoal, percent | Oil, percent | Oxygen-percent of requirement for complete combustion |
|---|---|---|---|---|---|---|---|
| M-7229 | 0.6 | 85.2 | 0.6 | 0.6 | 12.3 | 0.7 | 111 |
| M-7332 | .3 | 83.3 | 3.1 | .2 | 12.6 | .5 | 111 |
| M-7339 | .4 | 86.5 | (KCl + $KClO_3$=.1) | | 12.4 | .6 | 112 |



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Standard sample M-7229 failed to pass the fiber-shoe pendulum-friction test, showing a hazardous friction sensitivity. The sample was not sensitive enough to fail the pressure-friction test. Samples M-7332 and M-7339, containing more and less chlorate, respectively, than sample M-7229 passed the fiber-shoe pendulum-friction test. The results are not conclusive because foreign matter was observed in sample M-7229 and the samples were not dried before testing. Sample M-7229 was insensitive to static spark, both unconfined and confined; unconfined samples were not affected by small amounts of chlorates. Sample M-7229 and others containing up to 3 percent chlorate had high ignition temperatures, 325° to 387° C.; there was no obvious effect due to the presence of chlorate. The three samples showed the same sensitivity in the brass-cup impact test; with the 5-kg. weight, the lower limit was 20 cm. and the upper limit 50 cm. - sensitivity comparable to that of tetryl. Above 300° C., the lower limit for M-7229 did not change from that at room temperature in the brass-cup impact test; the upper limit, however, was lower at the higher temperature. Large-scale impact tests showed that preignited samples were extremely sensitive to impact. Unignited samples required a fall of 8.0 feet for a 45-pound weight to affect initiation; preignited samples with the same weight gave a detonation with a fall of only 5 inches. When confinement was heavy enough sample M-7229 detonated, the rate of detonation being about 2,050 meters per second. Chlorate appreciably increased the detonation rate when only 3 percent was present. From combined experimental methods a value of pressure between 23,200 and 26,950 p.s.i. for sample M-7229 was determined to be the pressure at which change from deflagration to burning bordering on detonation or actual detonation occurred. Comparisons were made with a chlorate mixture which was deemed hazardous because an explosion had occurred during its manufacture. The chlorate mixture showed greater sensitivity to impact and heat and a higher detonation rate; the spark sensitivity of this mixture showed no hazard. The mixture, contrary to the action of all others, exploded on testing with the steel shoe; however, it passed the fiber-shoe tests. This sample has not been analyzed, and friction sensitivity was determined on samples that were not dried.

The standard mixture M-7229, on the basis of tests made to date, is only extraordinarily hazardous where friction may be encountered or where the possibility of a blow on the burning mixture exists. Tests on ignition temperature and static spark sensitivity show no great hazard. The brasscup impact tests indicate that the mixture has an inpact sensitivity comparable to tetryl and greater than TNT. Contrary to the beliefs of some, the mixture will detonate if the confinement is heavy enough. The detonation rate is considerably lower than that of military high explosives. Potassium perchlorate per se at elevated temperatures could not be brought to explosion by direct mild impact and did not explode at ordinary and elevated temperatures when subjected to high velocity impact and detonation while confined. Explosion of potassium perchlorate mixed with underoxidized products of explosion from neighboring explosives such as tetryl may readily occur.. Potassium perchlorate did not explode by heat shock, although decomposition under such conditions appeared rapid enough to produce pressure higher than atmospheric around the decomposing mass.



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Surface Storage of Explosives

Satisfactory storage facilities have not generally been provided for explosives at the operations where used.45/ This condition was emphasized by inspections of explosive magazines by Bureau engineers in administration of the Federal Explosives Act and revealed the inadequacy of the magazines as well as hazards caused by improper storage. Remodeling of old magazines or construction of new ones is needed to afford suitable protection against fire, deterioration, and detonation of explosives. The fundamental features of suitable magazines are shown by sketches and drawings, and recommended types of constructions are listed. Safe procedures in operating explosive magazines are given.

Disposal of Deteriorated Explosives

The problem of destroying explosives that have become unfit for use or are unsuited to any need at their location is occasionally presented to Bureau representatives. Authoritative information indicates that most explosives, except detonators, are best destroyed by burning.46/ Methods of handling and burning various types of explosives and alternative methods of disposal and precautions to be taken are described.

Ignition Temperatures of Isobutane-Air Mixtures

Ignition temperatures of mixtures of isobutane in air were determined by the "static" method in a 131-cc. quartz bulb. Seven mixtures of known percentages of isobutane ranging from 2.18 to 10.55 percent by volume in air were tested. The minimum ignition temperature was found to be 464° C. for a mixture containing 9.68 percent of isobutane and 90.32 percent by air.

Prevention of Benzene-Air Explosions by Addition of Inert Gases

Earlier studies by the Bureau of Mines have developed procedures whereby the explosibility of many complex gaseous mixtures may be calculated in a rather simple manner without the necessity of performing laborious laboratory experiments. These studies have been of great benefit to the mining and other industries in eliminating, or at least mitigating, the explosion hazards of various combustible gases. The extensive use of complex gaseous mixtures containing various percentages of benzene vapor in the solvent industry and in the manufacture of high explosives emphasized the need of data on the limits of inflammability of benzene-air mixtures alone and on such mixtures to which various volumes of inert gases had been added, both in the lower- and upper-limit ranges. A report giving essential data required for the calculation of complex combustible gaseous mixtures containing varying percentages of benzene was issued.47/ Graphs and tables were prepared from experimental data which

45/ Harrington, D., and Warncke, R. G., Surface Storage of Explosives: Bureau of Mines Inf. Circ. 7307, 1945, 16 pp.

46/ Leitch, R. D., and Moyer, P. R., Destruction of Damaged, Deteriorated, or Unwanted Commercial Explosives: Bureau of Mines Inf. Circ. 7335, 1945, 6 pp.

47/ Jones, G., W., Prevention of Benzene-Air Explosions by Addition of Nitrogen, and Carbon Dioxide: Bureau of Mines Rept. of Investigations 3787, 1944, 20 pp.



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show the inflammable areas of all possible mixtures of benzene vapor, air, and added nitrogen and of benzene vapor, air, and added carbon dioxide. By means of these graphs and tables, the limits of inflammability of complex gaseous mixtures containing benzene may be calculated, and the percentages of oxygen in the mixtures that must not be exceeded to prevent the mixtures from becoming inflammable may be determined. The limits of inflammability of benzene in air were determined to be 1.40 percent by volume of benzene vapor for the lower and 7.10 percent for the upper limit of inflammability. Results obtained on benzene-air-nitrogen mixtures covering their entire range of inflammability showed that at least 21.2 volumes of nitrogen must be added for each volume of benzene vapor to make all mixtures with air noninflammable. Similar tests with benzene-air-carbon dioxide mixtures showed that the extinctive effect of carbon dioxide was greater than that of nitrogen; only 12.9 volumes of carbon dioxide per volume of benzene vapor were required to render all mixtures noninflammable. The ratio between the volumes of carbon dioxide and nitrogen, 12.9:21.2, equals 0.61. This value is close to the average ratio of 0.57 experimentally found necessary to render 1 volume of benzene, of 11 other hydrocarbons, or of carbon monoxide noninflammable under all conditions of dilution with air. The reason for this close relationship appears to be the relative heat capacity of nitrogen and carbon dioxide. If it is assumed that the flame-propagating temperature for the 13 different combustible gases tested was 1,400° C., the mean molar heat capacity between laboratory temperature and 1,400° C. is, by calculation, 7.46 for nitrogen and 11.85 for carbon dioxide. If the extinctive effect of the added inert gas is due entirely to its heat-absorbing capacity, the relative efficiency of two inert gases for extinguishing flames should be proportioned to their heat capacities or inversely proportional to their volumes required to extinguish 1 volume of the different combustible hydrocarbons. This ratio of heat capacity of nitrogen to that of carbon dioxide is 7.46:11.85 = 0.63, whereas the ratio by volume of carbon dioxide to nitrogen required to extinguish 1 volume of benzene vapor is 0.61. These values agree well with the average value of 0.57 found for benzene vapor, 11 other hydrocarbons, and carbon monoxide. Therefore, if the volume of nitrogen or of carbon dioxide required to extinguish the flame of a given combustible gaseous mixture is known, the volume of the other inert gas needed may be calculated with fair accuracy by using this average ratio. The use of inert gases to dilute explosive atmospheres and thereby dilute the air or oxygen concentration to the point where the mixtures become noninflammable has found many applications in recent years. Data of the type just described have proved of great benefit to industry. By applying this information, combustible mixtures containing benzene can be removed safely from containers and equipment or the mixtures may be introduced into such vessels originally containing air without creating inflammable atmospheres, if the proper volumes of inert gases - nitrogen or carbon dioxide, or a mixture of the two - are present in the proper concentration.

Acetylene-Generator Explosions

Information on the ignition temperatures of acetylene and of acetylene-air mixtures has been of particular interest in recent years due to a number of explosions that have occurred in 500-pound, double-rated, medium-pressure acetylene generators. The range of pressures in these generators may vary ...



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from below atmospheric to 15 pounds gage. Air may find its way into the generators during abnormal operation or may remain in the carbide hopper of the generator following the purging and charging operations. A study was made to determine the effects of pressure on the ignition temperature of pure acetylene and of acetylene containing varying amounts of air.48/ A special "hot-spot" ignition-temperature apparatus was developed to reduce the violence of the explosions by keeping most of the test mixtures at room temperature and using a heated quartz-ignition tube of 17 mm. or less I.D. At atmospheric pressure acetylene showed an ignition temperature of 635° C.; at 15 pounds per square inch above atmospheric the ignition temperature was reduced to 540° C. Addition of up to 10 percent of air to acetylene decreased the ignition temperature of acetylene only to a small extent; however, the pressure of 15 percent or more of air reduced the ignition temperature by 200° C. or more below that of pure acetylene at any given pressure. Acetylene containing 15 percent of air showed an ignition temperature (320° to 340° C.), only slightly higher than mixtures containing up to 75 percent of air (305° to 315° C.).

## PREPARATION OF COAL

### Recovery of Waste Coal

In normal prewar mining practices developed during pioneer days in the United States when its coal reserves were considered to be inexhaustible, it was common procedure to discard varying proportions of unmarketable coal, to leave parts of the coal bed unmined, and to pick out and throw away slightly off-grade coal during preparation. A tentative survey showed that such wastes exist in virtually every mining field of the country and are the results of many factors, such as the mine location, differences in natural conditions of the coal beds, and local mining practices. In the aggregate, these losses of off-grade coals amount to a large yearly tonnage, which, it is believed, can be largely recovered as usable fuel by the application of modern coal-preparation methods. A careful series of preparation tests of such material, now wasted on the surface at the rate of 2,500 tons a day by one group of mines near Pittsburgh, Pa., showed that this could be profitably treated to recover about 20 to 30 percent of the raw material as good steam coal of 9 to 11 percent ash content and 13,560 B.t.u. per pound heating value. Projected studies of this kind, in other fields, offer great possibilities for economy in use of fuel reserves in the postwar period. Furthermore, such investigations, extended to cover the industry as a whole, will uncover opportunities for new and attractive local industries connected with the recovery and utilization of this material.

### Preparation of Special Low-Ash Coal

In connection with the Synthetic Liquid Fuels Program, in which very low ash coal is needed, an extensive project was initiated to examine available

48/ Jones, G. W., and Kennedy, R. E., Effect of Pressure on the Ignition Temperature of Acetylene and Acetylene-Air Mixtures: Bureau of Mines Rept. of Investigations 3809, 1945, 6 pp.



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coals, particularly low-cost coals of very large reserve volume and to develop supercoal cleaning methods to treat these coals.

Ash is so deleterious in coal used in the hydrogenation process for producing synthetic liquid fuel that the coal employed for this purpose must be cleaned to an ash content lower than the limit usually considered economical. In making the separation between coal and impurity in the finer sizes, such as 14-mesh, the flotation process offers the most promise. Accordingly, flotation tests were made on 14-mesh coal from the Pittsburgh bed in the Bureau's Experimental mine at Bruceton. Kerosine was superior to all other reagents tried. With a single recleaning of the froth, the ash was reduced from 7.3 to 3.3 percent; the yield of clean coal at this ash content amounted to 58.5 percent. Float-and-sink tests indicate that about 50 percent of the coal is available at 2.0 percent ash, but none of the flotation reagents tried was selective enough to give a product of this quality.

Fourteen midwestern and western coals were sampled and tested by a newly developed technique of very close gravity float-and-sink testing. These tests showed that nearly all the coals examined contain fractions amounting to as much as 50 percent of the total raw material of an ash content as low as 2.5 percent. This fact was established by separating the samples at very low specific gravities - substantially below the range of current coal-washing practice - so as to separate the pieces of very pure coal from the pieces slightly higher in ash. Thus, if separations could be made at such precise gravities, any of the corresponding products indicated could be obtained. Results of detailed float-and-sink studies on the possibilities of producing an exceptionally low-ash product from Pittsburgh bed, Bruceton mine, bituminous coal were published.[49/] Figure 15, taken from this publication, represents graphically a typical coal specific-gravity consist. Each horizontal black band represents a certain portion of the sample differing from the adjacent band by 0.01 specific gravity. The first column at the right shows the yield by cumulative weight and the second column the cumulative ash content of the washed coal that would be obtained by cutting the raw coal in the washery along the specific gravity line indicated by the specific gravity indicated at the left side of the chart.

## Removal of Extraneous Material from Coal

A pilot-plant unit, based on a new Bureau of Mines process for cleaning and dewatering the fine sizes of coal found around coal-preparation plants, was installed by the cooperating company in Alabama. The results so far obtained are satisfactory with respect to ash reduction, to recovery, and to dewatering of coal; capacity is still somewhat in doubt. To obtain required data as to the capacities of 2-cell and 4-cell combinations, the company plans to install another unit.

The feasibility of using concentrating tables for recovering coke breeze from old beehive coke dumps has been demonstrated, under Bureau of Mines supervision, at one plant.

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49/ Fraser, T., Crentz, W. L., Cooper, H. M., Abernethy, R. F., and Barrett, O. T., Low-Gravity Float-and-Sink Separations of Bituminous Coal Samples: Bureau of Mines Rept. of Investigations 3812, 1945, 11 pp.



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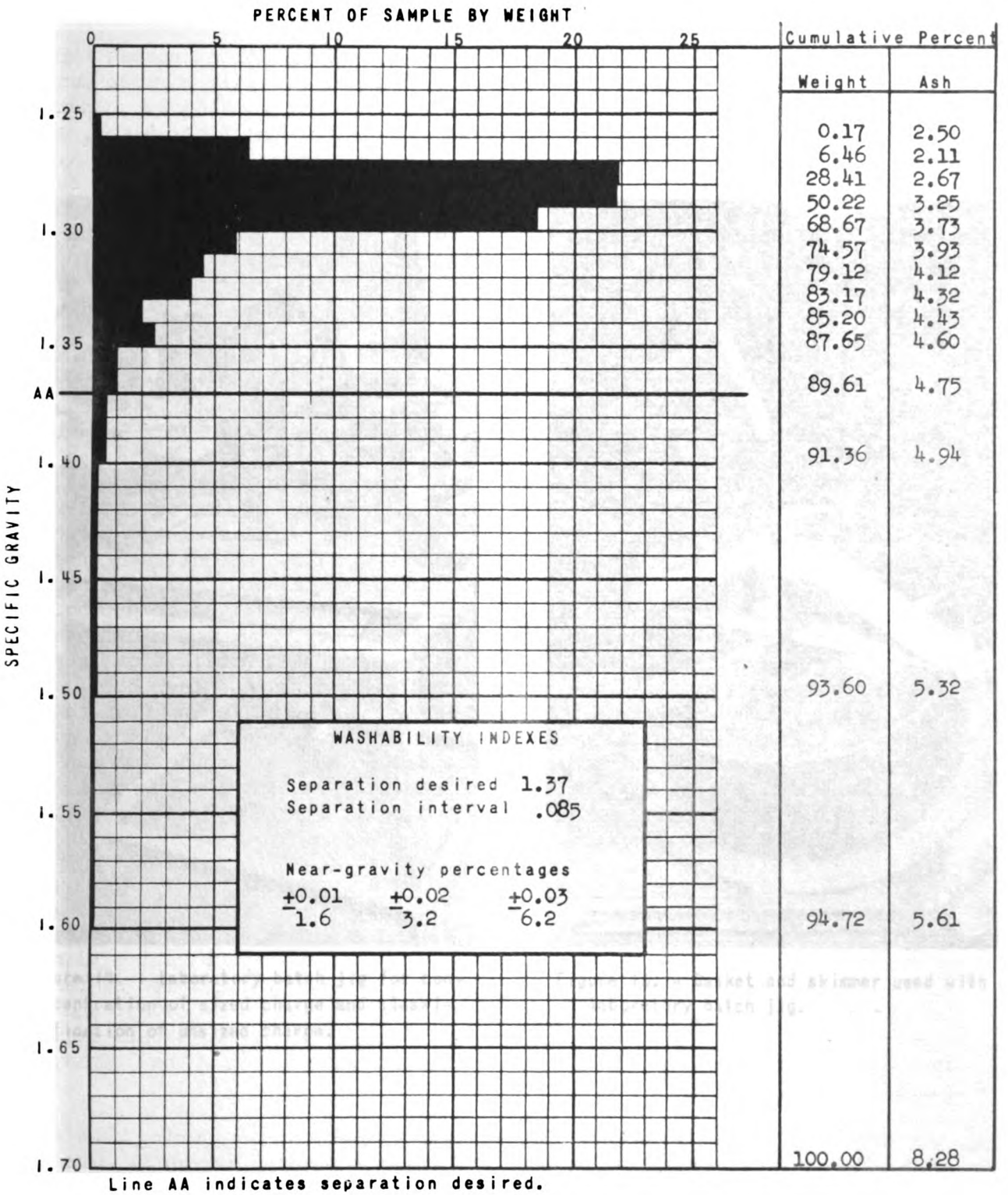


Figure 13. - Chart of typical coal specific-gravity consist.

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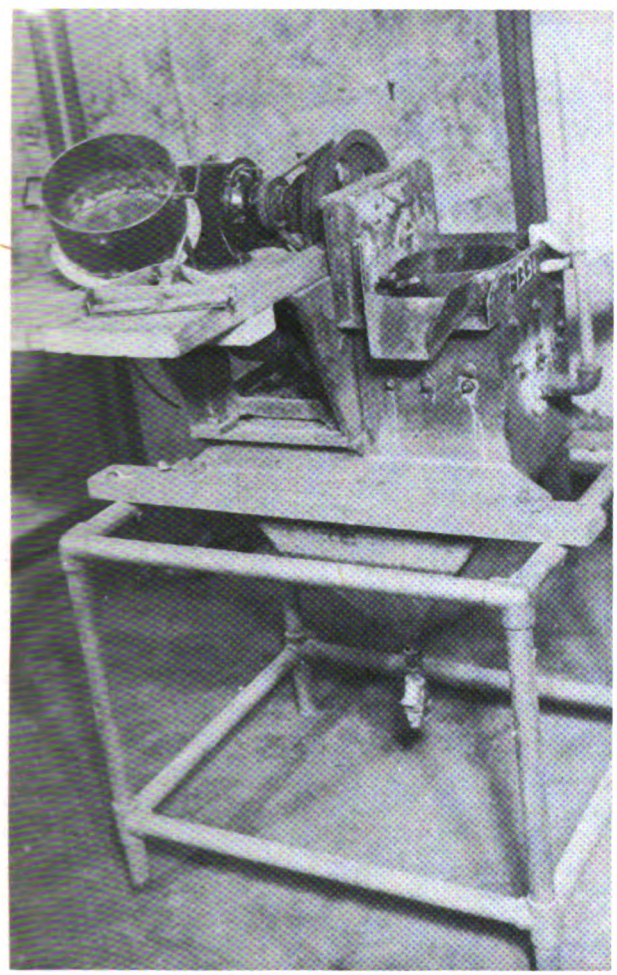

Figure 14. - Laboratory batch jig for concentration of sized charge and classification of unsized charge.

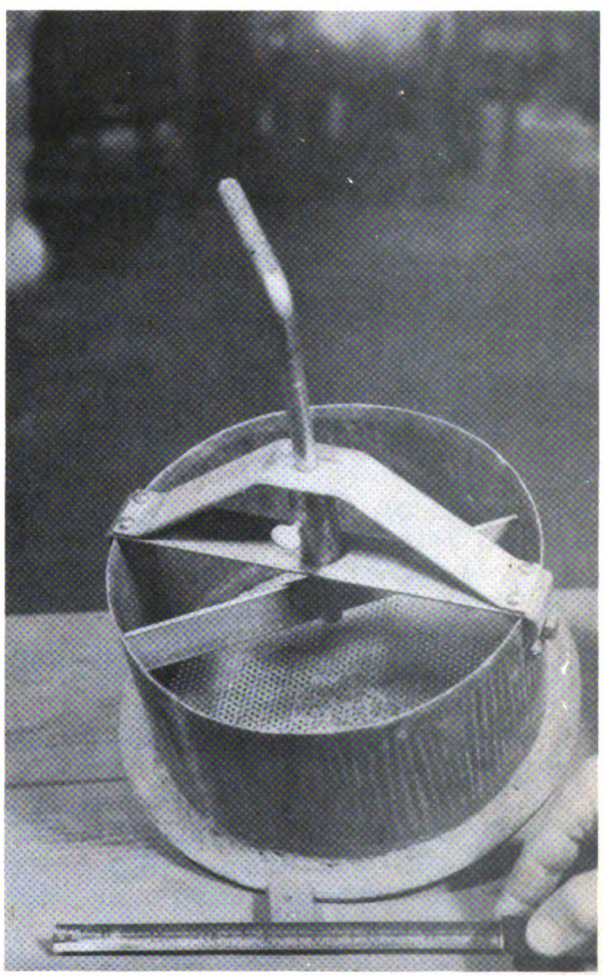

Figure 15. - Basket and skimmer used with laboratory batch jig.

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Those engaged in washing coal on tables have long realized the need of a nonchoking hydraulic classifier. As a result of Bureau of Mines research, this nonchoking feature was provided by a "periodic pincer" which insures a constant and controlled flow of particles through an oversize orifice.50/ With some modifications in design, the classifier and pincer are being used in the laboratory to treat 3 tons of coal per hour. It is planned to use two small tables in the unit to demonstrate the advantages of classification for tabling.

## Precision Jigging of Coal

All gravity-concentration processes, even including the new heavy-media processes, are influenced to some degree by particle size and shape. Although specific gravity is usually considered the predominating influence in these separations, size and shape under some circumstances may completely counteract the effect of specific gravity. Laboratory float-and-sink separations fail to appraise the size and shape effects. For this reason, in interpreting float-and-sink data, it is necessary to allow for the effect of such factors as particle size and shape and a general plant efficiency factor. The precision jig furnishes experimental data to facilitate this practical interpretation of basic washability data. A laboratory batch jig of unusual precision was developed to supplement washability data obtained by standard float-and-sink tests.51/

Figure 14 shows the jig and figure 15 the basket and skimmer. In using the jig a removable basket 9 inches in diameter and 7 inches in depth is amply large for coal not coarser than 0.5-inch diameter. The use of about 6 pounds of steel punchings to form a layer about 0.5 inch deep provides uniform distribution of water throughout the bed. Before the coal is added to the basket, the punchings are jigged for several minutes with a long stroke and with much water for leveling and orientation. The jigging of a sized feed has been found to be equally effective for predominately pulsion or predominately suction action. To reduce hutching suction should be avoided, and to prevent the overflowing of fine, light particles (28- to 35-mesh) the pulsion should not be excessive. In a test with fine material, it was quite easy to achieve a balance between plunger stroke and hydraulic water, so that the bed opens on the pulsion stroke but does not overflow the basket. A pretreatment with a wetting reagent is required for fine coal. Upon removal of the basket, as many strata as may be desired can be skimmed off.

Table 7 contains data from float-and-sink and batch-jig testing of 14- to 20-mesh and 3/8-inch to 3-mesh raw coal. For each size, the weight, percent is obtained by the float-and-sink fractionation. The determined ash contents of the float-and-sink fractions are recorded and the ash contents of

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50/ Coe, C. D., and Coghill, W. H., Periodic Pincer to Control flow of Wet Ore Pulp through an Orifice: Bureau of Mines Rept. of Investigations 3750, 1944, 6 pp.

51/ Coe, C. D., and Coghill, W. H., Precision Jigging as a Substitute for Laboratory Sink-Float: Bureau of Mines Rept. of Investigations 3769, 1944, 7 pp.



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the jig fractions of corresponding weight percent were calculated from the batch-jig comulative curves. The float-and-sink data for the 14- to 20-mesh size show that 54.1 percent of the sample is coal with an average ash content of 5.8 percent. By this jig, the ash content of the corresponding fraction was 7.9 percent. These data illustrate the application of the test jig in estimating probable commercial jig performance by reference to the fundamental specific-gravity characteristic of the coal.

TABLE 7. - Comparison of precision batch jigging with float-and-sink fractionation of raw coal

14- to 20-mesh

| Specific gravity | Weight percent | Ash in specific-gravity fractions | Batch-jig ash, percent |
|---|---|---|---|
| Float 1.30 | 54.1 | 5.8 | 7.9 |
| 1.30 -1.38 | 24.5 | 14.5 | 10.8 |
| 1.38 -1.50 | 10.1 | 23.0 | 22.0 |
| 1.50 -1.70 | 3.8 | 36.2 | 37.1 |
| Sink -1.70 | 7.5 | 75.9 | 72.7 |
| | 100.0 | 16.1 | 16.1 |

3/8-inch to 3-mesh

| Specific gravity | Weight percent | Ash in specific-gravity fractions | Batch-jig ash, percent |
|---|---|---|---|
| Float 1.30 | 21.1 | 6.9 | 8.4 |
| 1.30 -1.38 | 50.8 | 11.8 | 11.8 |
| 1.38 -1.50 | 11.2 | 20.0 | 24.9 |
| 1.50 -1.70 | 4.6 | 32.7 | 39.4 |
| Sink -1.70 | 12.3 | 77.3 | 69.4 |
| | 100.0 | 20.7 | 20.8 |

## Characteristics of Coal-Cleaning Processes

The performance characteristics of coal-cleaning processes must be considered in selecting equipment for a particular application; with coals that are difficult to clean, performance is of primary importance. A recent report[52/] provides a detailed comparison of the performance of three commonly used units treating the same coal - a pneumatic jig known as the air-flow cleaner, a pneumatic table, and a Baum-type jig. The pneumatic jig and pneumatic table effected ash reductions of 1.6 and 2.0 percent, respectively, at efficiencies of 92.5 and 95.9 percent; in comparison, the Baum-type jig reduced the ash content by 6.5 percent and operated at an efficiency of 97.1 percent. In all three cleaning units, the sharpness of the separation effected between clean coal and impurity decreased with decrease in particle size. With both pneumatic units the modifying effect of particle size was so marked that no cleaning was accomplished in the material finer than

52/ Yancey, H. F., and Geer, M. R., Coal-cleaning Performance - Comparison of Pneumatic Jig, Pneumatic Table, and Baum-type Jig: Am. Inst. Min. and Met. Eng., Tech. Pub. 1888, 1945, 16 pp.



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28-mesh. With the Baum-type jig, however, the efficiency of the separation between coal and refuse was influenced much less by particle size and a substantial reduction in ash content was effected in the sizes finer than 20-mesh.

## Chemistry of Coal Cleaning

The relation of chemistry to the cleaning of coal was described in a chapter of a recent book published under the auspices of the National Research Council.[53] Coal cleaning touches the field of chemistry principally in flotation, the flocculation of slurry, dustproofing, the extraction of ash-forming impurities by treatment with acids, and heavy-media processes. These aspects of coal cleaning are critically reviewed. Also included in the chapter is a discussion of the impurities occurring in coal that are removable by cleaning, and the effect of their removal on utilization.

## Preparation Tests of Toledo, Wash., Lignite

One of the few coal deposits in Washington that offers promise of being amenable to strip mining is a bed of lignite occurring near Toledo in Lewis County. Exploration by private companies indicated that the lignite averages about 40 feet in thickness and that the cover averages some 43 feet. Added interest attaches to this property because it is within 20 miles by highway of a high-grade clay deposit at Castle Rock. Since improving the quality of the coal appeared to be the critical factor upon which development of the property depends, the Bureau of Mines undertook coal-preparation tests to determine the quality of coal that could be produced and the treatment needed to prepare it for the market.[54] This investigation showed that coal obtainable from the deposit near Toledo, Wash., would contain not less than 33 percent moisture and 12 to 17 percent ash on the bed-moisture basis or 19 to 25 percent on the moisture-free basis, depending upon the size of coal and method of preparation. The heating value on the bed-moisture basis would be 6,000 to 6,500 B.t.u. per pound. If mined cheaply by stripping, the coal could be used as a low-cost fuel in a suitably designed boiler plant near the property; owing to its low calorific value, however, it probably could not be shipped in competition with high-grade coals to more distant points of consumption.

## Miscellaneous Washability Examinations

Washability examinations and in some instances washing tests were made on coals from Alaska, Montana, Oregon, and Washington. Some of these coals were from new mines that are being developed; others were from mines at which cleaning plants will be required to provide coal of better quality for the

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53/ Yancey, H. F., and Geer, M. R., The Cleaning of Coal: Nat. Research Council (H. H. Lowry, ed.), Chemistry of Coal Utilization, New York, vol. 1, 1945, pp. 572-599

54/ Yancey, H. F., and Geer, M. R., Preparation Tests of Lignite from a Deposit near Toledo, Lewis County, Wash.: Bureau of Mines Rept. of Investigations 3795, 1945, 14 pp.



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postwar market. Recent washability data for Alabama coals are being used by mining companies in designing preparation plants at two mines recently put into production.

Reclaiming of Beehive Coke

Small coke that was discarded by the beehive industry for many decades because it was not acceptable to industrial consumers at the time of production was removed during the war from old coke dumps and reclaimed by screening, hand picking, and occasionally washing operations. Coke from western Pennsylvania dumps alone furnished about 250,000 tons of badly needed solid fuel during the year. The major part of this reclaiming was done by small operators; because it was of temporary nature, no facilities were installed to determine the quality of output. At the request of the Solid Fuels Administration for War, Bureau engineers visited and sampled the product at almost all such plants at least once during the year. Operators were kept informed on all developments for expediting production or improving the quality of this emergency fuel. Results of all analyses of the product were furnished the Solid Fuels Administration so that the consuming public was protected against unscrupulous operators. The best operators produced coke of an ash content ranging from 14 to 25 percent, whereas poor operators sold some reclaimed coal having an ash content as high or higher than 35 percent.

## STORAGE OF COAL

### Action of Coal in Storage

Activities on the storage of coal included laboratory investigations of the relative tendency of 28 coals to heat spontaneously and interpretations and correlations of the data obtained with observed field experiences in the storage of these and similar coals. Most of these coals were tested at the request of the War Department. Representative bituminous and subbituminous coals from 8 States in this country and from the Lota and Schwager mining areas in Chile, South America, were tested. The coals included: 2 medium-volatile bituminous coals - 1 from Alabama and 1 from West Virginia; 7 high-volatile A bituminous coals - 1 from Alabama, 1 from Colorado, 1 from West Virginia, and 4 from Chile; 9 high-volatile B bituminous coals - 2 from Colorado, 2 from Illinois, 1 from Indiana, 3 from Kentucky, and 1 from Missouri; 8 high-volatile C bituminous coals - 1 from Colorado, 1 from Illinois, 2 from Indiana, 3 from Missouri, and 1 from Ohio; and 2 subbituminous A coals - 1 from Oregon and 1 from Wyoming. Although considerable variation in heating tendency was observed for individual coals within the several ranges of rank, averages for the several ranks proved the general rule that the tendency of a coal to heat spontaneously in storage varies inversely with its rank. Moreover, check tests on individual coals made under comparable conditions by another method in which the rate of consumption of oxygen is determined at 212° F. in air gave close agreement with results obtained by this direct adiabatic calorimeter test. For the several ranges in rank, the averages of comparative self-heating rates at 212° F. in the adiabatic calorimeter test, based on a value of 1 for a typical, high-volatile A bituminous, Pittsburgh bed, coal, were: Medium-volatile 0.80; high volatile A, 2.9; high-volatile



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B, 6.7; high-volatile C, 10.8; and subbituminous A, 7.2. The last value is low because these 2 subbituminous A coals had already oxidized appreciably when received for test; earlier work on two other subbituminous A coals gave a value of 14.1

A paper describing the adiabatic calorimeter test method for determining the spontaneous heating tendency of coal and summarizing the results obtained on 39 bituminous and 6 subbituminous coals and 1 lignite was published.[55/] Results on several of the coals tested during the present fiscal year were included. It was found that the spontaneous-heating tendencies of coals depend on: (1) The nature or rank of the coal, the heating increasing with decreasing rank; (2) the temperature at which the coal is stored, the rate of reaction increasing very rapidly with rise in temperature; (3) the past history of the coal, the reaction rate decreasing rapidly with increased time of storage and quantity of oxygen consumed; (4) the availability of oxygen, the rate of oxidation being proportional to the oxygen concentration in contact with the coal raised to the 0.66 power; (5) the particle size and effective surface area, the rate of oxidation being proportional to the cube root of the surface area; and (6) the moisture and ash content of the coal, which tend to reduce relative spontaneous tendencies because of the latent heat of vaporization and high specific heat of water and the inert diluting effect of the ash.

Consulting Service to Government Establishments

Upon request, consulting service on various coal-storage problems was given to several Government establishments and industries. Consulting service was given to the War Department on a fire in a coal pile in Missouri; on the heating tendencies and storage of Bevier, Mo., coal; on methods of storage of Coos Bay, Oreg., coal; and on storage of coal and temperature measurement in coal piles at Fort Belvoir, Va. A study was made for the War Department of various proposed formulas for determining the amount of coal in storage piles of three specific shapes; a simplified scheme was developed for making such estimates. Another study at Camp Carson, Colo., for the War Department provided new information on storing lump subbituminous coal. Consulting service was given to the Navy Department on determining the amount of coal in storage, and on methods of storing coal at the Washington Navy Yard. The Bureau of Mines furnished material and assisted the Navy Department in preparing a bulletin on coal handling and storage for distribution to the various land plants of the Navy. A series of questions and answers covering home storage of subbituminous coal was prepared at the request of the Division of Solid Fuels Administration for War for use in a campaign to induce householders to store such coal during the summer, thus supplying domestic needs and alleviating production and distribution loads in the later months. Consulting services were given to the Department of Justice on the storage of subbituminous coal at Englewood, Colo.; to the Public Buildings Administration on sprays for coal-storage piles; and to the Hanna Coal Co. of Ohio on the difficulties of coal storage at many different locations.

55/ Elder, J. L., Schmidt, L. D., Steiner, W. A., and Davis, J. D., Relative Spontaneous Heating Tendencies of Coals: Bureau of Mines Tech. Paper 681, 1945, 24 pp.



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Effect of Oxidation on Physical and Chemical Properties of Coal

A comprehensive article discussing the significant changes in the physical and chemical properties of coal that occur upon exposure to air at atmospheric temperatures was published.56/ Changes observed in storage piles, studies of the rate of the oxidation reaction under controlled conditions, characteristic rates of oxidation of various coals, the mechanism of the oxidation reaction and the influence of the physical structure of coal, methods of measuring relative tendencies toward spontaneous ignition, the effect of oxidation on the properties of coal, and the relative storability of various coals were discussed. Various factors, such as temperature, oxygen concentration, and particle size and composition of the coal, that affect the storage properties of coal, its combustion characteristics, and the yields and quality of its carbonization products, were considered in detail.

## UTILIZATION OF COAL

### Combustion

Fuel-Engineering Service

Fuel-engineering service to Government establishments with respect to the selection and use of fuels and fuel-burning equipment was continued. Special surveys of various problems were made at requests of the Navy Department, the War Department, the National Housing Agency, the Veterans Administration, the Department of Agriculture, the Department of Justice, and a number of Government heating plants in the Washington, (D.C.), area. Studies and analyses of the corrosive deposits on boiler tubes and the economizer at the Washington Navy Yard power plant showed them to be high in sulfates resulting from sulfur dioxide and sulfur trioxide in the products of combustion. Similar boilers and fuel-burning equipment using the same coal did not experience such deposits. Special collecting tubes that could be kept at various temperatures were used in numerous places throughout the path of the products of combustion. It was found that the accumulation of deposits depends on the type of fuel-burning equipment, the amount of sulfur in and the type of coal, the temperatures of the gases and the tubes, and apparently the amount of fly ash. At the request of the Navy Department, studies were made of two boilers at an industrial plant at Hopewell, Va., and at a public utility plant in Washington, D. C. Products of combustion were analyzed for sulfur trioxide content; the A.S.T.M. code method for making such tests was found to be unsatisfactory. Changes in stoker operation gave some relief; special equipment to affect combustion is being installed in one boiler. Troublesome boiler-tube deposits which forced operators to take each boiler off the line every 2 to 4 weeks at the Naval Aviation Supply Depot at Philadelphia, Pa., were analyzed, as well as the ash from three anthracite coals then used; slagging was prevented by eliminating use of two of the coals. The proper type of coal and the amount of coal required for a proposed Navy project in Vermont

56/ Schmidt, L. D., Changes in Coal During Storage: Nat. Research Council (H. H. Lowry, ed.), Chemistry of Coal Utilization, New York, Vol. 1, 1945, pp. 627-676.



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were determined. Studies were begun to determine the fuel efficiency at each plant under the command of the Army Regional Headquarters, Ninth Service Command, at Salt Lake City, Utah. At requests of the National Housing Agency, specifications were studied and recommendations made covering refractory plastics and fire brick for furnaces at Greenbelt, Md.; a talk on coal conservation and boiler-plant maintenance was given before a conference of superintendents of projects at New York City. At requests of the Veterans Administration, over-all operating costs using different fuels were determined for plants at Grand Junction, Colo., Wilmington, Del., Kansas City, Mo., Peckskill, N. Y., Salisbury, N. C., Pittsburgh, Pa., and Providence, R. I. Decisions as to coal size were made for plants at Lyons, N. J., and Lakeside, Fla., and type of fuel and equipment for its use were determined for a project at Fargo, N. Dak. A series of three talks on fuel efficiency and boiler-plant operation was given before a group of boiler-plant engineers from Veterans Administration plants in the general vicinity of Chicago, Ill. At requests of the Department of Agriculture, a survey was made at Beltsville, Md., of the Central Office heating plant to determine needed changes in furnace design and proper coal for use, and an investigation was conducted of the overloading of a motor driving an induced-draft fan at the boiler plant of the Horticultural Station. Furnace changes needed for burning slabs at the Mill Point, W. Va., project were studied at the request of the Department of Justice. The amount of added condenser water needed and the piping required to bring this water from the Anacostia River were determined and recommendations made on proposed new equipment at the Capitol Power Plant. Specifications for stokers, prepared by the Purchasing Division of the Department of Interior, for Klingle Mansion, Washington, D. C., were studied and changes and recommendations were made. Specifications were reviewed, changes made, and resulting bids analyzed for boiler feed-water requirements at Howard University. Work was continued on the contract change order of new power-plant equipment for St. Elizabeths Hospital. An acceptance test run on a new deaerator showed unsatisfactory and unacceptable performance; changes were made, and a test run showed a satisfactory outcome. A new condenser pump had to be replaced because of unsatisfactory performance. A proposed lay-out for new boilers, including type, size, and type of fuel-burning equipment, was determined for the Bureau of Mines Station at Bruceton, Pa. Specifications for boilers and stokers were studied and changes recommended; bids on boilers and stokers were analyzed and recommendations made as to acceptance. A cooperative study by the Air Preheater Corporation, New York City, and the Bureau of Mines has been planned at a public utility plant in Indianapolis, Ind. Tests will be made on different kinds of construction materials to determine corrosion and deposit effects; weights and thicknesses of various types of test plates to be used in the study have already been determined by laboratory investigations.

## Boiler Feed-Water Conditioning

Analyses and resulting recommendations were made on 18,185 samples of water during the fiscal year as follows: 16,610 samples from the War Department, 610 from the Veterans Administration; 345 from the Office of Indian Affairs; 214 from the Department of Justice; 186 from District plants; 67 from the Post Office Department; 54 from the United States Public Health Service; 49 from the National Housing Agency; 24 from the Navy Department; 22



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from the Department of Agriculture; 2 from the War Relocation Authority; and 2 from the Bureau of Mines. Reports were made on analyses of 11 boiler compounds, 30 boiler scales and sludges, and 10 oil contaminations. One hundred and eighty-three special Bureau of Mines field water test kits, 13,511 bottles of chemical reagents, and 13,939 test-kit replacement items were distributed, mostly to Army posts. At the request of the Maritime Commission, a study was made of boiler feed-water pump corrosion difficulties on ships; special tests were made on the stability of cyclohexylamine at high pressure and temperatures. At the request of the War Department, a study was made of boiler-water treatment and recommendations made as to choice and amount of chemicals to be used in locomotives operated by the Army. At the request of the Procurement Division, a study was made of a proposed method for analyzing polyphosphates, and a different method was developed for use. At requests of the Veterans Administration, a new test procedure was developed for analyzing chloride content, and boiler feed-water conditioning was discussed before a group of engineers from Veterans' plants in the Chicago area. A study was made of the accuracy of the yellow spot diameter method of testing for phosphate and the effect of bleaching of tannin on the phosphate test; a report on this work was made at a meeting of War Department boiler-water engineers at Atlanta, Ga. At the request of the District Government, a study was made of foaming difficulties caused by a boiler-water compound used for sealing cracks in cast-iron boilers; experiments with and analyses of the compound resulted in eliminating its further use. A new test kit was developed for determining sodium sulfate in boiler water and an instruction booklet completed; directions were prepared for field testing of tannin. A boiler inspection was made by request at the Jefferson Junior High School, Washington, D. C. Consulting service on various other problems of boiler feed-water conditioning was given to 30 Government agencies. To help boiler operators who have not studied chemistry to understand the essentials of boiler feed-water conditioning, questions and answers on this subject have been published.57/ This publication is a reprint of part of a 132-page booklet of the same title and by the same author, published as Bureau of Mines Question and Answer Handbook 3 in 1936.

A paper describing the use of cyclohexylamine for preventing corrosion in steam-heating systems, discussed in last year's report, was republished and abstracted in several publications.58/

## Boiler Feed-Water Research

The heavy investment of more than $300,000,000 in steam-heating systems at Army camps alone and rapid deterioration of a part of the piping under

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57/ Barkley, J. F., Questions and Answers on Boiler Feed-Water Conditioning: Coal-Heat, vol. 46, October 1944, pp. 50, 53-54; vol. 47, January 1945, pp. 35, 38-39; February 1945, pp. 40-41, 56; March 1945, pp. 50-51, 57.

58/ Berk, A. A., Observations on the Use of Cyclohexylamine in Steam Heating Systems: Proc. Nat. District Heating Assoc., vol. 35, 1944, pp. 172-189; discussion, pp. 189-193. Abs. Steam Eng., vol. 14, December 1944, pp. 78-80; Power, vol. 89, March 1945, pp. 71-73, 146, 148; Power Plant Eng., vol. 49, May 1945, pp. 130, 132.



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corrosive conditions have emphasized the need of developing more effective methods of treating boiler water for use in such systems. Cyclohexylamine, although useful in correcting corrosive conditions, has several limitations. Preliminary observations in the laboratory and in an operating steam system showed that the amine volatilized from the boiler water and neutralized the carbon dioxide acidity in the condensate steam, but because of high volatility excessive quantities of the amine were lost at vents. Moreover, the neutralized carbon dioxide, instead of being lost at the feed-water-heater vent, was recirculated with the amine in the condensate returned as boiler feed water. Economical treatment requires not only maximum recirculation of the amine but also minimum recirculation of the carbon dioxide. It appeared probable that an amine of more desirable properties would provide a more economical treatment. On the other hand, the use of cyclohexylamine offers distinct advantages as a local injection into single pieces of equipment, such as large hot-water generators, in which carbon dioxide tends to concentrate dangerously with respect to corrosion. A comprehensive study of amine treatments is now in progress. The behavior of compounds of widely different volatilities and alkalinities is being studied in thousands of samples of condensate steam taken from a typical heating system. Testers were placed in the piping to detect whether any of the compounds used have special merit in preventing corrosion. It is expected that this study will define the properties and characteristics of the most economical amine treatment for any particular steam-heating system.

Embrittlement cracking in boiler seams has been caused by concentrated potassium hydroxide. It is entirely feasible to operate high-pressure boilers with water which contains no free potassium hydroxide, but which is alkaline by virtue of its content of potassium phosphate and silicate. Correlation of the results of hundred of embrittlement detector tests, made according to the tentative method of the American Society for Testing Materials,[59] with boiler water analyses showed that the nitrate treatment of preventing embrittlement cracking has been entirely successful. Quebracho extract has also proved satisfactory in many instances. Tests in high-pressure boilers have shown that use of phosphates in a preferred method of treatment and has been adopted by many power plants. In some instances, it has been possible to correlate the results of embrittlement detector tests with actual failures in stationary power plants.

## Fly-Ash Separator for Use in Homes

Improvements in design of a simple, practicable, gravitational-type fly-ash separator, recently developed for use in homes, were suggested.[60]

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59/ American Society for Testing Materials, Tentative Method of Field Test for Tendency of Boiler Water to Cause Embrittlement Cracking of Steel, A.S.T.M. Designation D 807-44T: A.S.T.M. Standards, 1944, pt. III, Nonmetallic Materials, pp. 2099-2105.

60/ Barkley, J. F., Discussion of "The Fly-Ash Problem with Domestic Stokers and the Use of Settling Chambers and Firebox Baffles," by T. S. Spicer, R. G. Bowman, and C. C. Wright: Trans. Am. Inst. Min. and Met. Eng., Coal Div., vol. 157, 1944, pp. 244-245.



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Suggestions included a gate instead of a removable cap on the baffled settling chamber for dumping the ash from the hopper and a side plate on the device to provide easy access to the interior.

## Smoke Abatement

Work was continued by the Model Smoke Law Committee of the American Society of Mechanical Engineers on the preparation of a model smoke law. A summary to provide a basis for establishing dust-load limitations was made of test data on the amount of "dust" emitted in the products of combustion by different types of fuel-burning equipment at various loads and on the dust-catching efficiency of present-day dust collectors. Two meetings of the committee were held at New York City and one at Pittsburgh. A semifinal draft of all sections and comments covering about 5 years' work was completed; it is planned this coming year to complete the work now assigned to this committee. Consulting service on various problems connected with smoke abatement was given to city officials in Los Angeles, Calif., Washington, D. C., and Tacoma, Wash.

## National Fuel Efficiency Program

Work was continued on establishing and maintaining a network of active volunteer coal-conservation workers. The chief objectives of the program centered around a Nation-wide effort to conserve all fuels through their more efficient utilization. The program was under the general guidance of the National Fuel Efficiency Council, composed of fuel engineers of national reputation. The council held two general meetings during the year and carried out many individual assignments. Some 190 coordinators directed the program on fuel conservation in their individual areas. About 830 engineers and industrialists of outstanding reputation locally served on advisory committees of the various coordinators. Some 5,000 volunteer engineers made plant surveys and obtained the cooperation of more than 13,000 plant owners and organizations, who then appointed employees as "waste chasers" in individual plants to direct the engineering work of saving fuel. In addition to the personnel of the Washington, D. C., central office, district engineers, with offices at Chicago, Ill., Indianapolis, Ind., and Kansas City, Mo., and two other district engineers visited the coordinators and their committees as aides in establishing and maintaining the program in all of the areas.

Various general meetings were held in different cities, and talks were made before both national and local societies and groups. Appropriate literature was prepared to acquaint operating personnel with the best methods of operating power and heating plant equipment to effect maximum fuel conservation. Twenty-nine new waste chasers' quiz sheets were issued during the fiscal year. Upon requests, a total of 1,244,804 copies of these 29 and 16 other earlier-published quiz sheets were distributed; a total of 363,798 copies of single-sheet explanatory memoranda accompanied 10 of the quiz sheets. Three new quiz sheets are in press, and 5 are in preparation. Check sheets numbering 16,275 copies on industrial furnaces, 17,443 on heating plants, and 49,301 on industrial boiler plants were distributed to the waste chasers. A total of 1,150 copies of Recommended Procedure for Coordinators and 54,223 copies



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of the Brief of Regional Engineer's Procedure[61] were distributed. Publicity on the National Fuel Efficiency Program was furnished gratuitously by many companies. This publicity was in the form of 4 colored posters, 67 articles in industrial and technical publications and house organs, advertising space in magazines, and a broadcast over a national radio hook-up; posters distributed by request numbered 54,223. Three hundred copies of 3 publicity press releases were distributed to all new coordinators for publication in local newspapers. Nine press releases covering the development of the program were distributed to the general press through the Office of War Information.

As an example of how the campaign to save fuel operates, the field survey work in plants in one district of the Pittsburgh, Pa., area will be summarized briefly. Seventy-five man-days were spent in the field inspecting 146 heating plants. The territory covered was predominantly residential; 77 of the visits were made to apartment houses burning an average of 185 tons of coal each per year. Other plants, such as hospitals, schools, central heating plants, and commercial establishments, had higher average consumption; the total annual tonnage burned in all plants inspected was 74,600. No relationship could be detected between the size of the plant and the efficiency of operation or the physical condition of the equipment. The fuel savings possible, therefore, appear to be nearly independent of the size of plant in the range of 50 to 15,000 tons annual consumption of coal. Based on estimated savings possible, approximately 6,500 tons of coal could be conserved in this one Pittsburgh district or 87 tons of coal saved per man-day of inspection time if the recommendations of the regional engineers were followed.

Among the many articles describing the work of the National Fuel Efficiency Program, the following may be mentioned as representative.[62]

## Properties of Coal Ash as Related to Clinkering and Slagging

Excessive accumulations of slag on the heat-absorbing surfaces of large central-station boiler furnaces often cause difficulties in operation and interfere seriously with the expected transfer of heat from the furnace through the boiler tube to produce steam. As a result, not only may the circulation

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61/ Brief of Regional Engineer's Procedure: Nat. Eng., vol. 49, March 1945, pp. 196-198.

62/ Cheasley, T. C., Work of the National Fuel Efficiency Program: Min. Cong. Jour., vol. 30, December 1944, pp. 26-28; Proc. Illinois Mining Inst., Oct. 27, 1944, pp. 24-29; discussion, pp. 29-31; Smoke (Official Bull. Smoke Prevention Assoc. America, Inc.), vol. 11, June 1944, 2 pp.
Barkley, J. F., Fuel Conservation: Manual of Instructions on Proper Firing Methods (Official Pub., Smoke Prevention Assoc. America, Inc.), 1945, pp. 1-12.
The National Fuel Efficiency Program: Solid Fuel Eng., vol. 3, August 1944, pp. 8-10; Nat. Eng., vol. 48, September 1944, pp. 588-604; October 1944, pp. 641-656, 673; vol. 49, April 1945, pp. 278, 280; Heating, Piping, and Air Conditioning, vol. 16, November 1944, pp. 65, 66, 621, 628, and 640; The Rochester Engineer, vol. 23, January 1945, p. 93.



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of water and steam within the boiler be affected, with possible damage to some tubes, but superheat control is difficult, and oftentimes the output of the boiler must be decreased to permit operation within safe temperature limits. Cleaning of these badly fouled surfaces during operation usually requires excessive labor; if the deposits occur in inaccessible locations, it is often necessary to shut down the boiler, with resultant loss of steaming capacity of the power plant. Studies over the past several years of the physical properties of coal-ash slags at high temperatures have furnished much needed fundamental information from which it has been possible to analyze the factors controlling the thickness of these slag deposits.63/ Such factors are divided into two classes, one fixed by the properties of the slag and the other dependent upon furnace conditions. For the slag, not only is the viscosity of the liquid portion important, but also the "temperature of critical viscosity" at which the slag changes from a fluid to a plastic state on slow cooling. Since both the viscosity and the temperature of critical viscosity are related to composition, it is possible to predice the relative thickness of slag deposits for different slags of known composition under idealized furnace conditions. Figure 16 shows the relative thickness of slag deposits of a wide range of compositions in terms of the total iron content computed as $Fe_2O_3$, the amount of CaO present, and the ferric percentage, which is a measure of the state of oxidation of the iron forms. Although computed for the case where the furnace side of the deposit is at a temperature of 2,800° F. and the cold side in contact with the tube is at 1,200° F., similar plots can be made for other furnace conditions. In general, for fixed furnace conditions, increased temperature of critical viscosity and increased viscosity of the slag cause approximately equal increases in the thickness of the slag deposit. However, as the temperature of critical viscosity approaches that of the furnace side of the slag deposit, there is a large increase in thickness, independent of the viscosity. Increase in the iron content of the slag, as well as increase in the fraction of the iron in the ferrous state, decreases the thickness of the deposit. The relative thickness is also decreased by increase in the CaO content, the effect being greatest with slags containing less than 20 percent equivalent $Fe_2O_3$.

## Thermal Conductivity of Coal-Ash Slags

To obtain data on the rate at which heat is transferred through deposits of coal-ash slags, and to furnish information on slag characteristics to better understand the action of slag in large industrial furnaces, a study is being conducted in cooperation with the Special Research Committee on Furnace Performance Factors of the American Society of Mechanical Engineers. Design and construction of the experimental apparatus is now 95 percent complete. Methods of measuring the thermal conductivity of liquids are more difficult than with solid materials, and problems resulting from measuring temperatures as high as 2,700° F. further complicate the design of equipment. The principle used is to confine the molten slag in the annular space between two concentric platinum alloy cylinders; thermocouples attached to the cylinders

63/ Reid, W. T., and Cohen, P., Factors Affecting the Thickness of Coal-Ash Slag on Furnace-Wall Tubes: Trans. Am. Soc. Mech. Eng., vol. 66, 1944, pp. 685-690; abs. Combustion, vol. 16, July 1944, pp. 42, 44.



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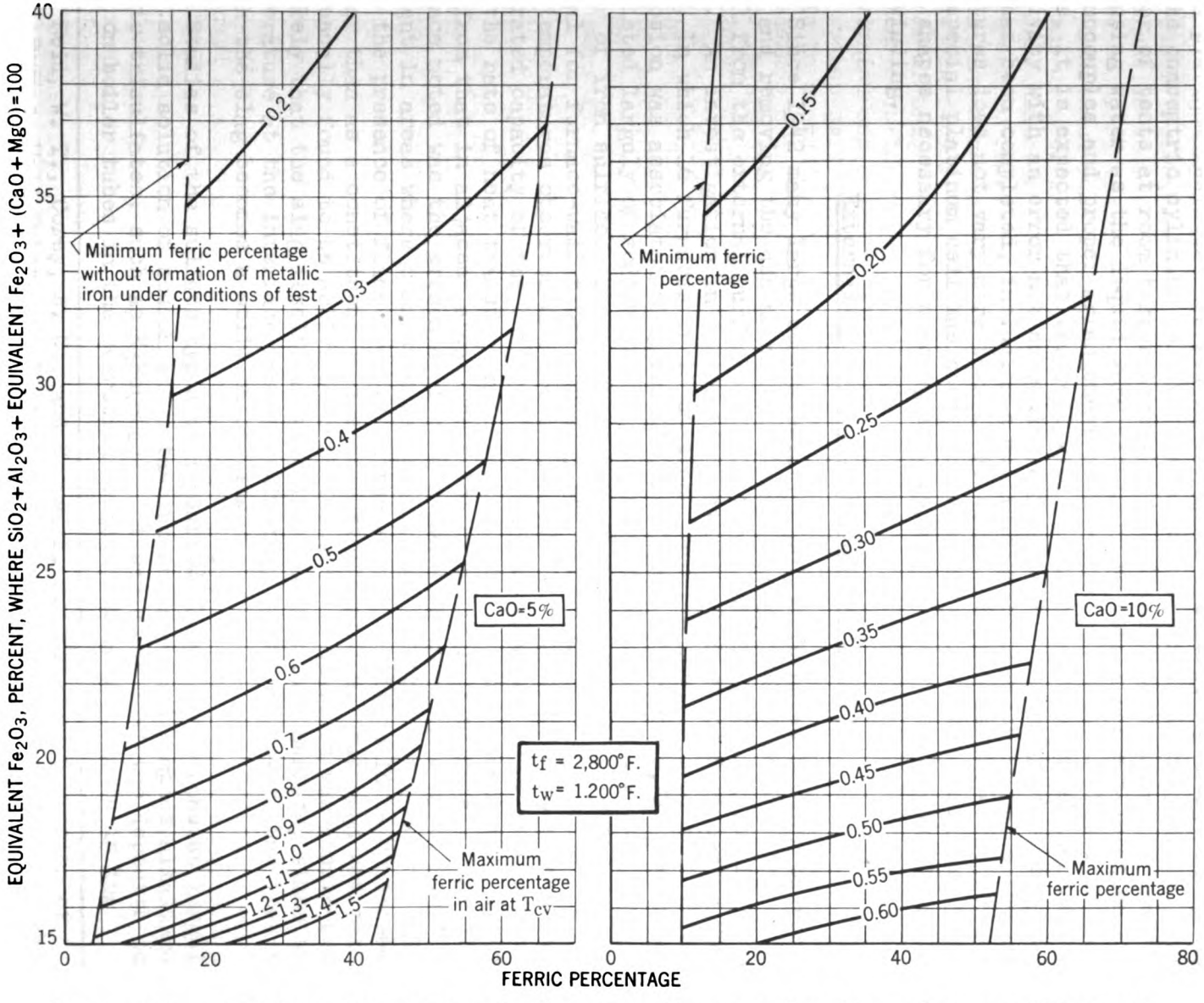


Figure 16. - Relative thickness of slag deposits as a function of composition and ferric percentage for a silica : alumina ratio of 2 : 1.

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permit measurement of the thermal gradient due to the flow of heat from the inner to the outer cylinder through the slag, the heat being generated by a small platinum resistor inserted in the inner cylinder. Although the design of the concentric cylinder cell was based on mathematical analyses, a large number of tests at room temperature with model cells constructed of brass and using water as the liquid were necessary to obtain correct location of thermocouples and proper arrangement of the internal heater. Based on these tests, it is expected that the cell will permit measurements of thermal conductivity with an error not exceeding ± 5 percent. Assembly of other apparatus has been completed, including a multiple-wound furnace in which the temperatures does not vary more than 2° F. along a 6-inch length at 2,600° F. The special platinum cell has been received, as well as the intricate porcelain shapes necessary for spacing and support of thermocouples and the internal winding.

## External Corrosion of Furnace-Wall Tubes

Since 1942 many large central-station boiler furnaces burning pulverized coal and removing the ash as molten slag have experienced severe loss of metal from the external surfaces of the tubes making up the walls of the furnace. An investigation in cooperation with the Combustion Engineering Company, in which 16 furnaces in 13 stations were examined, showed that this corrosion was associated with two distinct types of deposits,[64] one of which consisted largely of sodium and potassium sulfate in a complex form, and the other of iron sulfide. This corrosion was found to occur at temperatures normal for furnace-wall tubes, usually not exceeding 700° F., while the maximum temperatures observed did not exceed 900° F. Rates of heat release and the rated capacity of the boilers in which corrosion was found were nominal, and the rate of heat transfer in corrosion areas was not essentially different from that in adjacent areas where there was no loss of metal. One difference noted was the presence of carbon monoxide in amounts up to about 5 percent in areas where corrosion was occurring, but this was taken to indicate the presence of flame from which the alkali metals could be condensed, rather than as a constituent in the corrosion eeaction. Although corrosion was usually found to be active beneath deposits of slag, it was considered unlikely that the slag itself was reacting with the tube surface, since the temperature at the interface was approximately 1,000° F. lower than that at which the slag becomes a solid on cooling.

Studies of the sulfate types of deposit[65] showed it to consist largely of a solid solution of sodium and potassium sulfates and complex alkali-metal ferric trisulfates, such as $K_3Fe(SO_4)_3$. It was shown that the deposits occurring on boiler tubes in the corrosion areas could be reproduced in the

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64/ Reid, W. T., Corey, R. C., and Cross, B. J., External Corrosion of Furnace-Wall Tubes - I. History and Occurrence: Trans. Am. Soc. Mach. Eng., vol. 67, 1945, pp. 279-288.

65/ Corey, R. C., Cross, B. J., and Reid, W. T., External Corrosion of Furnace-Wall Tubes - II. Significance of Sulfate Deposits and Sulfur Trioxide in Corrosion Mechanism: Trans. Am. Soc. Mech. Eng., vol. 67, 1945, pp. 289-302.



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laboratory by heating a mixture of sodium or potassium sulfate and iron oxide at temperatures up to 1,000° F. in an atmosphere containing small amounts of $SO_3$. These reactions suggested that the mechanism of corrosion involved the removal of the normally protective oxide on the furnace tube by (a) condensation on the relatively cool tubes of alkali-metal oxides from the flame in the furnace, these oxides being converted to the sulfate by the small amount of $SO_3$ normally present in the furnace gases, and (b) subsequent reaction of the iron oxide on the tube and the alkali-metal sulfates with the larger amounts of $SO_3$ evolved as the result of slagging reactions in the coal ash deposited mechanically in that area. Figure 17 illustrates the entire series of reactions, including the final state at E, where deslagging has removed the slag layer and exposed the reaction products to high temperatures, causing their decomposition. To prevent external corrosion, it would be necessary (a) to use a tube or to protect its surface with a metal or alloy which alkali-metal sulfates and $SO_3$ do not affect, or (b) to prevent these constituents from reaching the tube surface in sufficient concentration to be dangerous. By means of burner changes or "air-belting," the tube surfaces, in some instances, have been sufficiently well ventilated with air to prevent further corrosion. It is believed that the beneficial results are principally from dilution and that the disappearance of carbon monoxide at the point of corrosion can be taken as evidence of ample ventilation. Experimental evidence is lacking on the need of flame contact to deposit alkali-metal oxides or sulfates on the tube surface. If it is shown that the flame envelope is the principal source of the alkalies, then the presence of air along the wall would prevent deposition of alkalies and effectively stop further corrosion. Work is being continued on this phase, as well as on the mechanism of formation of the sulfide-type deposits.

## Utilization of Mixtures of Bituminous Coal and Anthracite

The Solid Fuels Administration for War has encouraged the use of anthracite fines: (1) To alleviate the general fuel shortage in the Eastern states; (2) to find increased markets for the fines incidental to the production of domestic sizes of anthracite; and (3) to relieve the acute shortage of low-volatile bituminous coking coal by decreasing the quantity required in coke-oven mixes through the substitution of anthracite fines. The Bureau of Mines has cooperated in the technical problems involved to meet these objectives.

Plant studies and tests were continued throughout the Eastern Seaboard regional headquarters of the War Department. This work included an initial survey, a general plan of procedure, and training of plant operators. Where it appeared that anthracite fines could be added, further tests were made on mixtures with bituminous coal; this work resulted in the continued use of anthracite fines at many plants using 30 to 50 percent of anthracite. At many plants, studies showed that too many boilers were being used to carry the load; much equipment, particularly control equipment, was not in proper working order; and low efficiencies were being obtained. In all instances, higher efficiencies and, consequently, large annual savings resulted from the work. Examples of these savings included: Fort Devens, Mass., laundry plants, $5,000; Lovell General Hospital, $8,500; Waltham General Hospital, $15,500; and Presque Isle, Maine, laundry and hospital plant, $21,700. Mixtures of bituminous coal and anthracite were used successfully



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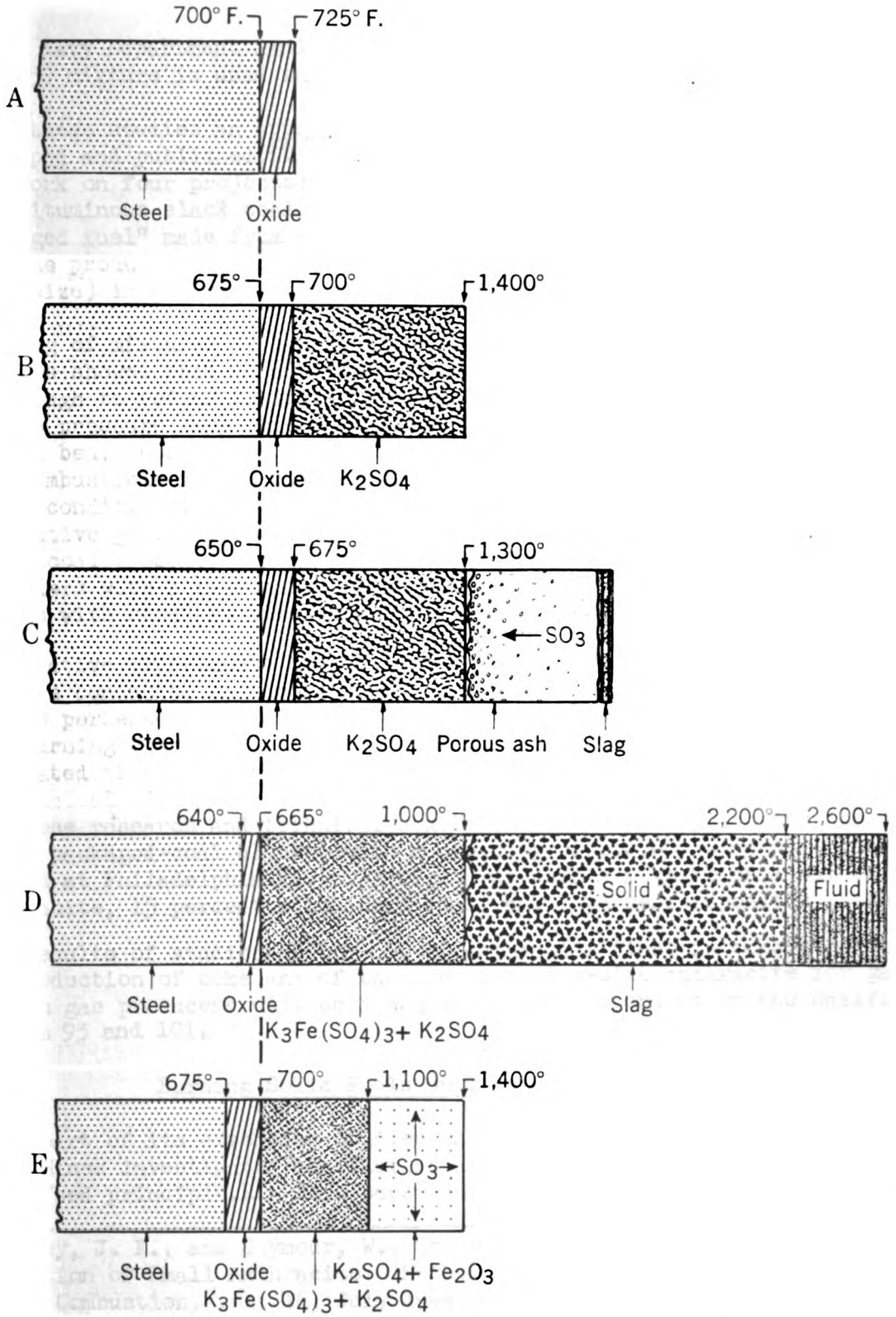


**Figure 17. - Mechanism of corrosion of wall tubes by sulfate deposits.**

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at several Navy Department land projects in the Eastern area; at Bainbridge, Md., a 50:50 mixture is used in all the equipment.

From these studies an appreciable amount of new technical information was developed and published.66/ This paper summarizes the results of Bureau of Mines work on four projects: (a) The burning of mixtures of small anthracite and bituminous slack coal on stokers; (b) methods of producing and burning "packaged fuel" made from anthracite fines; (c) the use of anthracite fines in the production of coke; and (d) the use of barley anthracite (No. 3 Buckwheat size) in gas producers.

Burning of mixtures of barley anthracite and bituminous slack on underfeed stokers showed that an addition of about 15 percent of anthracite was usually enough to reduce caking. Increased percentages of anthracite decreased the pressure drop through the fuel bed, decreased the manual attention to the fuel bed, decreased the smoke, increased the fly ash, increased the unburned combustible in the fly ash and refuse, and, in general, improved the clinkering conditions. The load-carrying capacity of the stoker was affected by the relative proportions, compositions, and properties of anthracite and bituminous coal present. In general, the efficiencies obtained on single-retort stokers with a reasonable range of anthracite admixtures were about the same as with straight bituminous coal.

Cooperative experiments by the Bureau of Mines and a large industrial company were conducted on the manufacture and testing of coal blocks containing various percentages of anthracite fines. Physical and chemical properties and burning characteristics of packaged fuel produced in experimental runs indicated that large percentages of anthracite fines could be successfully briquetted with bituminous coal by use of an asphaltic binder. As a result of these research and technical studies, a commercial plant for the production of packaged-coal blocks, with a capacity of 150,000 tons per year, was erected at Philadelphia Pa. The first run used a mixture of about 80 percent anthracite, 15 percent bituminous coal, and 5 percent asphaltic pitch.

The results of studies of the use of anthracite fines in coke-oven mixes for the production of coke and of the use of barley-size anthracite for gasification in gas producers will be discussed under Carbonization and Gasification, pages 93 and 101.

## Burning Solid Fuels on Traveling Grates

As a part of its extensive studies on burning solid fuels on grates, the Bureau of Mines investigated the factors affecting the burning of fuels on the cross-feed principle.67/ This paper describes the study of ignition travel

66/ Barkley, J. F., and Seymour, W., The War Problems of Increasing the Utilization of Small Anthracite: Mech. Eng., vol. 67, 1945, pp. 457-462. Abs. Combustion, vol. 16, July 1944, p. 41; Coke and Smokeless-Fuel Age, vol. 6, December 1944, p. 240.

67/ Carman, E. P., and Reid, W. T., Ignition Through Fuel Beds on Traveling-or Chain-Grate Stokers: Trans. Am. Soc. Mech. Eng., vol. 67, 1945, pp. 425-463; discussion, pp. 436-437.



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through a fuel bed and the important factors affecting it. The investigation was conducted in relatively small-scale laboratory apparatus where the many variables involved were subject to close control. The study showed that in fuel beds on traveling-grate stokers ignition and burning proceed according to unrestricted underfeed principles until ignition reaches the grate. At constant air rate, underfeed ignition proceeds at a steady rate unless certain factors alter the air distribution or fuel-bed characteristics. These factors include development of blowholes, with consequent maldistribution of air; turbulence or "boiling" of the bed, which may give mechanical mixing of ignited and unignited fuel; slow initial ignition; drying of moist coal before ignition; heating of coal with preheated primary air; and burning of highly reactive fuels in very thin burning layers. After ignition reaches the grate, burning is overfeed, and increase of air will give proportional increase of burning rate, at least within the range where stable bed conditions prevail. Slow initial ignition of the top layer of fuel on traveling-grate stokers is followed by relatively slow rates of ignition travel through the bed, being slowest at the top, increasing with progress of ignition into the bed, and tending to approach, as ignition nears the grates, the steady, higher ignition rates found with rapid initial ignition. Rates of ignition as affected by added moisture, size of fuel particle, preheating of primary air, ash content of coal, and the use of high-temperature coke, coke breeze, anthracite, high-volatile A and C bituminous coals, subbituminous B coal, and lignite were thoroughly considered in relation to air rates, burning rates of the fuel, and fuel-bed characteristics.

Certain factors affecting the burning of solid fuels on traveling grates were studied further during the past fiscal year. Tests were made on raw and on steam-dried lignite and on a Pennsylvania low-volatile bituminous coal. Observations of these thin fuel beds corroborated previous evidence that, with highly-reactive fuels where the burning layers are very thin, the effect of loss of heat to the environment is important in controlling the rate at which the plane of ignition travels through the raw fuel. Thus, the temperature of the furnace itself will affect the rate of travel of the plane of ignition by influencing the heat lost from the fuel bed by radiation; even decreased heat losses resulting from an overlying layer of spongy clinker increased the rate of travel perceptibly.

Because of the importance of disposing usefully of the smaller sizes of coal, a study was made of the burning properties of coals in sizes smaller than 3/32-inch to determine the limitations under which such coals can be burned successfully in this type of equipment. Such information is valuable not only during periods of fuel shortages such as resulted from the war, but also to improve the economic status of coal utilization during peace times by preventing needless waste of a useful product. Problems in the utilization of small coals and the recovery through up-grading of useful fuels from otherwise wasted colliery refuse in England and comparisons with certain American practices were reviewed.[68]

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68/ Reid, W. T., Review of "Proceedings of a Conference on Problems in the Utilization of Small Coals" (Brit. Coal Util. Research Assoc., London, Cheney and Sons, Branburg, England, 1944, 294 pp.: Jour. Appl. Physics, vol. 16, May 1945, p. 312



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## Burning Characteristics of Fuels

As a result of requests for information on the suitability of vaious fuels for domestic heating, laboratory apparatus was installed which permitted closely controlled tests of the burning characteristics of a wide variety of fuels. Based on a conventional cast-iron, sectional, hot-water boiler, this equipment permits measurements of the quantity of smoke produced, the rate of heat absorption, composition and temperature of the flue gas, pressure drop through the fuel bed, rate of burning, and efficiency. Equipped with a natural-draft chimney, mounted entirely inside the laboratory so that is is unaffected by winds or other variables, tests can be made in which the fuel itself determines its rate of burning. Automatic control equipment has been provided so that the rate of air supply can be varied in proportion to the demands of the burning fuel, or can be maintained at a fixed value. The provision of a special firing door containing protected windows allows inspection of the fire at any time or photographing the fuel bed without interference with the test. Either standard procedures or time-lapse motion pictures to accentuate actions occurring in the fuel bed are used. Tests have been made with this equipment of packaged fuel made from anthracite fines mixed with varying amounts of bituminous coal, of char made from high-volatile C bituminous coal, and of lignite briquets prepared experimentally from waste sizes of fuel.

## Stability and Structure of Burner Flames

The work described in last year's report on the structure and stability of flames has been published.69/ Further experiments were conducted on the air entrainment in Bunsen burners. Several series of data have been obtained by systematic changes of the gas flow, of the gas-orifice diameter, and of the length of the burner tube. The data are being analyzed and a series of experiments on Venturi-type burners now in progress will complete the investigation.

# CARBONIZATION AND GASIFICATION

Special studies were made of the carbonization properties of new low- and medium-volatile bituminous coals that might be used to increase the Nation's supply of coal of proved coking properties whose reserves are being rapidly depleted. Studies were also made of two Chile coals to assist the Chilean Government in establishing an iron-smelting industry.

## Small-Scale Laboratory Tests of Coking Coals

In connection with the Bureau of Mines-American Gas Association (BM-AGA) survey of gas- and coke-making properties of American coals, small-scale laboratory carbonization tests were made of coals from various States to determine their suitability for the production of coke. The tests included the

69/ von Elbe, G., and Mentser, M., Further Studies of the Structure and Stability of Burner Flames: Jour. Chem. Phys., vol. 13, 1945, pp. 89-100.



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the Fischer low-temperature carbonization assay, the United States Steel Corp. high-temperature distillation assay, and the Bureau of Mines agglutinating-value test. Coals tested were from the following sources: Washed coal from Hill bed, Hickey No. 1 mine, Fort Payne, Cherokee County, Ala.; No. 5 Block bed, No. 5 mine, Montcoal, Raleigh County, W. Va.; and Pocahontas No. 6 bed, Birdseye mine, Sewell, Fayette County, W. Va. In addition, high-temperature carbonization tests were made of a blast-furnace mix composed of 80 percent Fairmont- and 20 percent Beckley-bed coals and of a foundry-coke mix consisting of 53 percent Pittsburgh-bed coal, 43 percent Beckley-bed coal, and 4 percent No. 4 buckwheat-size anthracite. Results of small-scale laboratory carbonization tests of several coals have been incorporated in technical papers published or prepared for publication during the year. (See Exploration of Coal Deposits, p. 25 and Carbonization Properties of American Coals, p. 81).

Agglutinating-value tests were made of more than 120 diamond drill-core and mine samples of coal submitted in connection with projects for locating new sources of coking coal for steel plants and for proving coal reserves. The coals were from the following sources: Lookout Mountain field of northeastern Alabama and northwestern Georgia; Grand Mesa field near Paonia, Gunnison County, Colo.; Durango field in La Plata County, Colo.; Georges Creek field of western Maryland; Coaldale field in Esmeralda County, Nev.; Deep River field in Chatham County, N. C.; Northern field in Anderson County, Tenn.; and the New River field in West Virginia. Agglutinating values of drill-core samples from the Lookout Mountain field in Alabama ranged from 6.5 to 8.5 kilograms and those of mine samples from 0.7 to 7.0 kilograms. These agglutinating-value results, obtained at a 15:1 ratio of silicon carbide to coal, indicate that many of the coals are strongly coking. Low values for some of the mine samples are probably due to oxidation of the coal since some samples were collected from abandoned mines. The agglutinating values of Lookout Mountain coals of Georgia ranged from 4.8 to 8.7 kilograms, which are considered satisfactory for coking coal. The agglutinating values of the Georges Creek coals in Maryland ranged from 0.6 to 10.6 kilograms; the low values probably were due to oxidation of the coal. In Colorado, the La Plata County coals examined are probably fair-coking, and the Paonia coals range from nearly noncoking to fair-coking. The North Carolina, Tennessee, and West Virginia coals have agglutinating values that would classify them as fair- to good-coking.

Agglutinating values are an approximate measure of the extent of coal oxidation and therefore are of value in following the changes in the coking quality of coals during storage. In connection with a survey of storing quality of coals, the agglutinating values of 65 coal samples were determined during the year. The coals examined were from the following sources: Hill and Mary Lee beds of Alabama; Gunnison, La Plata, and Mesa Counties, Colo.; No. 5 and No. 6 beds of Illinois; No. 5 and No. 6 beds of Indiana; Elkhorn No. 3, Kentucky No. 11, and Kentucky No. 14 beds of Kentucky; Bevier and Walker beds of Missouri; Raton bed of New Mexico; No. 6 bed of Ohio; McAlester bed of Oklahoma; Pittsburgh bed of Pennsylvania; Roslyn No. 5 bed of Washington; Eagle, No. 5 Block, Pocahontas No. 3 and Pocahontas No. 6 beds of West Virginia; Finch bed of Wyoming; and Lota and Schwager areas of Chile.



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The free-swelling index by the A.S.T.M. Tentative Method of Test for Free-Swelling Index of Coal was determined for 10 samples of coal from stripping operations in Bedford and Clinton Counties, Pa., and in Garrett County, Md., in connection with the potential use of these coals as railroad locomotive fuels. The results showed that some of the coals were nonswelling and nearly noncaking and hence would be unsatisfactory for locomotive use, since the "stack losses" would be high because of coal blown off the grates.

In connection with a survey of carbonizing properties of coals of Chile, made at the request of the Chilean Government, agglutinating-value tests were made of 17 samples of coals and coal blends from the Lota and the Schwager mining areas. The values at the 15:1 silicon carbide:coal ratio ranged from 1.7 to 5.5 kilograms and show that most of the coals examined are of only fair coking quality. One coal tested from the Province of Valdivia and two near the Straits of Magellan were noncoking.

Free-swelling indexes and agglutinating values were determined on 11 samples of coal from the Feng and Lung mines at Peipay near Chungking, Szechwan Province, China. These tests were made at the request of the Foreign Economic Administration, which is assisting the Chinese Government in the development of its coal resources. The agglutinating values ranged from 3.9 to 8.4 kilograms and the free-swelling indexes from 1.5 to over 9. The agglutinating values and free-swelling results show that some of the coals are strongly coking. The ash content of the coals on a dry-coal basis ranged from 10.7 to 32.6 percent. It is possible that their coking properties can be improved by removal of extraneous ash by coal-washing methods.

## Carbonizing Properties of American Coals

Studies on the carbonizing properties, plasticity, expansion, and oxidation of coal were continued. Coals received for complete series of tests by the BM-AGA method of determining gas-, coke-, and byproduct-making properties were: (1) Hill bed, Hickey mine, Fort Payne, Cherokee County, Ala.; (2) No. 5 Block bed, No. 5 mine, Montcoal, Raleigh County, W. Va.; (3) Pocahontas No. 6 bed, Birdseye mine, Sewell, Fayette County, W. Va.; (4) a 50:50 composite of No. 3 bed, San Jose mine, and of No. 5 bed, San Pedro Sur mine, in the Schwager area, Chile; and (5) a 4:45:25:25 composite of Alta bed (Pique Nuevo mine), Alta bed (Pique Grande mine), Chica bed (Pique Grande mine), and Arriba bed (Pique Grande mine), respectively, in the Lota mining area. The Alabama coal and the two West Virginia coals were studied as part of an established program to increase the supply of domestic coking coals. Schwager and Lota coals were tested to determine their suitability, singly or in blends, for the manufacture of metallurgical coke in Chile. Medium-volatile bituminous Hill-bed coal was tested both in the unwashed and washed condition. The contents of coke and sulfur on the as-carbonized basis were reduced by washing from 6.1 to 2.3 and from 0.9 to 0.5 percent, respectively. No. 5 Block coal ranked as high-volatile A bituminous and contained 9.3 percent ash and 0.8 percent sulfur. Medium-volatile bituminous Pocahontas No. 6 bed coal contained 13.9 percent ash and 1.0 percent sulfur and probably would have to be washed to compete with other high-rank coals used in blends carbonized commercially. The composites of Schwager coals and of Lota coals



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also ranked as high-volatile A bituminous but lower in that classification than No. 5 Block-bed coal. The dry, mineral-matter-free, fixed-carbon contents of these three samples were 54.0, 55.1, and 63.4 percent, respectively. The Schwager composite contained 7.2 percent ash and 1.2 percent sulfur, and the Lota composite contained 7.4 percent ash and 2.1 percent sulfur, on the as-carbonized basis. These Chilean coals are somewhat similar in chemical properties to the Utah coking coals of the United States.

Table 8 gives the yields of carbonization products obtained on the as-carbonized basis by the BM-AGA method at 900° C. in 18-inch retort tests on the coals and coal blends named. Medium-volatile bituminous Hill- and Pocahontas No. 6-bed coals gave characteristic low yields of volatile products and high yields of coke. As would be expected from their respective ranks, the high-volatile A bituminous No. 5 Block-bed coal yielded less coke and more gas, tar, light oil, and ammonia than the medium-volatile bituminous coals. The high-volatile A bituminous Schwager and Lota coals, being lower in rank than the No. 5 Block-bed coal, yielded considerably less coke and more gas. Yields of carbonization products from the various coal blends, whose compositions are given in table 8, differed from those of their constituent coals in accordance with changes in rank resulting from blending.

Table 9 shows the physical and chemical properties of the gas. The heating values of gas from Pocahontas No. 6 coals are low, both on the basis of B.t.u. per cubic foot and as B.t.u. per pound; however, low heating values are characteristics of the high-temperature gases from medium-volatile bituminous coals. No. 5 Block coal ranks as high-volatile A bituminous, but the yield of gas as B.t.u. per pound was only 2,990; coals of this rank usually yield 3,100 to 3,400 B.t.u. per pound. The Chilean coals were better gas coals, Schwager and Lota composites yielding 3,650 to 3,480 B.t.u. per pound, respectively. In blending, heating values in gas generally were lowered when the rank of coal was raised, and raised when the rank was lowered. The gases from Hill and Pocahontas No. 6 coals did not contain excessive proportions of hydrogen sulfide. Washing the Hill coal decreased the content of hydrogen sulfide from 280 to 140 grains per 100 cubic feet. Gases from Schwager and Lota coals contained 670 to 520 grains per 100 cubic feet, respectively.

Tables 10 and 11, respectively, show the physical properties of cokes from the domestic and Chilean coals. The shatter and tumbler indexes of the Hill coke were satisfactorily high; they were lowered by blending with Pittsburgh-bed coal from the Warden mine. The coke from the unwashed sample was more abradable than that from the washed sample. No. 5 Block coke resisted shattering more than the average coke from high-volatile A coals; its 1/4-inch tumbler index (66.7) was relatively low, indicating high abradability. Blending with 20 and 30 percent Pocahontas No. 5 coal improved this coke appreciably. Pocahontas No. 6 coke resisted shattering well but did not resist abrasion in tumbling; reduction of the ash content of this coal probably would lower the abradability of its coke. Blending with Pittsburgh coal raised the 1/4-inch tumbler index appreciably but lowered the 2- and 1-1/2-inch shatter indexes.



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TABLE 8. - Yields of carbonization products, as-carbonized basis

Coal a87-100 percent Hill bed (unwashed)
Coal 87-100 percent Hill bed (washed)
Coal 87A-20 percent Hill bed (washed) and 80 percent Pittsburgh bed
Coal 87B-30 percent Hill bed (washed) and 70 percent Pittsburgh bed
Coal 88-100 percent No. 5 Block bed
Coal 88A-80 percent No. 5 Block bed and 20 percent Pocahontas No. 3 bed
Coal 88B-70 percent No. 5 Block bed and 30 percent Pocahontas No. 3 bed
Coal 89-100 percent Pocahontas No. 6 bed
Coal 89A-20 percent Pocahontas No. 6 bed and 80 percent Pittsburgh bed
Coal 89B-30 percent Pocahontas No. 6 bed and 70 percent Pittsburgh bed
Coal 228-100 percent Schwager composite
Coal 228A-90 percent Schwager composite (228) and 10 percent Pocahontas No. 3 bed
Coal 228B-90 percent Schwager composite (228) and 10 percent char
Coal 229-100 percent Lota composite
Coal 229A-90 percent Lota composite (229) and 10 percent Pocahontas No. 3 bed
Coal 229B-90 percent Lota composite (229) and 10 percent char

| | Yields, percent by weight of coal[1] | | | | | | | Yields per ton of coal[1] | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Coal No. | Coke | Gas | Tar | Light oil | Free ammonia | Liquor | Total | Gas, cubic feet | Tar, gallons | Light oil, gallons in gas | $(NH_4)_2SO_4$, pounds |
| a87 | 78.5 | 10.4 | 3.1 | 0.58 | 0.180 | 5.6 | 98.4 | 9,750 | 6.3 | 1.63 | 17.2 |
| 87 | 79.3 | 10.9 | 3.2 | .61 | .180 | 5.5 | 99.7 | 10,300 | 6.7 | 1.71 | 20.8 |
| 87A | 71.3 | 13.8 | 6.5 | 1.01 | .154 | 6.1 | 98.9 | 10,250 | 13.7 | 2.85 | 24.4 |
| 87B | 72.3 | 13.7 | 6.3 | 1.03 | .144 | 5.9 | 99.4 | 10,400 | 13.2 | 2.87 | 22.6 |
| 88 | 71.4 | 13.9 | 6.2 | 1.20 | .131 | 6.1 | 98.9 | 10,100 | 12.6 | 3.30 | 20.2 |
| 88A | 74.0 | 13.4 | 5.0 | 1.03 | .145 | 5.6 | 99.2 | 10,100 | 10.0 | 2.81 | 21.4 |
| 88B | 75.3 | 13.0 | 4.6 | .94 | .149 | 5.6 | 99.6 | 9,950 | 9.6 | 2.59 | 21.1 |
| 89 | 80.5 | 10.7 | 2.5 | .61 | .112 | 4.9 | 99.3 | 9,450 | 4.9 | 1.65 | 15.9 |
| 89A | 71.8 | 13.9 | 6.2 | .98 | .142 | 5.6 | 98.6 | 10,150 | 12.8 | 2.69 | 20.8 |
| 89B | 72.9 | 13.5 | 5.6 | 1.05 | .133 | 5.9 | 99.1 | 10,150 | 11.6 | 2.88 | 21.7 |
| 228 | 62.9 | 18.6 | 6.7 | 1.38 | .086 | 8.0 | 97.7 | 11,250 | 14.1 | 3.79 | 20.0 |
| 228A[2] | 65.2 | 18.0 | 6.0 | 1.27 | .089 | 7.3 | 97.9 | 11,100 | 12.5 | 3.48 | 18.9 |
| 228B[2] | 64.5 | 18.5 | 6.0 | 1.25 | .072 | 7.5 | 97.8 | 11,150 | 12.6 | 3.44 | 19.4 |
| 229[2] | 62.7 | 19.3 | 5.9 | 1.37 | .112 | 8.5 | 97.9 | 11,450 | 12.3 | 3.76 | 21.5 |
| 229A | 64.5 | 18.3 | 5.5 | 1.26 | .105 | 8.1 | 97.8 | 11,300 | 11.4 | 3.44 | 20.2 |
| 229B | 64.0 | - | 5.4 | 1.31 | .124 | 8.0 | - | - | 11.1 | 3.57 | 21.8 |

1/ Coke, tar, ammonia, and light oil are reported moisture-free; gas is reported as stripped of light oil and saturated with water vapor at 60° F. and under a pressure of 30 inches of mercury.

2/ Coal crushed to minus 1/8-inch.



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TABLE 9. - Physical and chemical properties of gas

Coal a87-100 percent Hill bed (unwashed)
Coal 87-100 percent Hill bed (washed)
Coal 87A-20 percent Hill bed (washed) and 80 percent Pittsburgh bed
Coal 87B-30 percent Hill bed (washed) and 70 percent Pittsburgh bed
Coal 88-100 percent No. 5 Block bed
Coal 88A-80 percent No. 5 Block bed and 20 percent Pocahontas No. 3 bed
Coal 88B-70 percent No. 5 Block bed and 30 percent Pocahontas No. 3 bed
Coal 89-100 percent Pocahontas No. 6 bed
Coal 89A-20 percent Pocahontas No. 6 bed and 80 percent Pittsburgh bed
Coal 89B-30 percent Pocahontas No. 6 bed and 70 percent Pittsburgh bed
Coal 228-100 percent Schwager composite
Coal 228A-90 percent Schwager composite (228) and 10 percent Pocahontas No. 3 bed
Coal 228B-90 percent Schwager composite (228) and 10 percent char
Coal 229-100 percent Lota composite
Coal 229A-90 percent Lota composite (229) and 10 percent Pocahontas No. 3 bed
Coal 229B-90 percent Lota composite (229) and 10 percent char

| Coal No. | Specific gravity | Gross heating value[1] | | | $H_2S$ grains per 100 cubic feet | Composition, dry, percent by volume | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | B.t.u. per cubic foot | | B.t.u. per pound of coal | | $CO_2$ | Illuminants | $O_2$ | $H_2$ | CO | $CH_4$ | $C_2H_6$ | $N_2$ |
| | | Determined | Calculated | | | | | | | | | | |
| a87 | 0.282 | 524 | 524 | 2,550 | 280 | 1.4 | 2.0 | 0.4 | 64.4 | 3.2 | 26.8 | 0.6 | 1.2 |
| 87 | .280 | 526 | 523 | 2,710 | 140 | 1.1 | 1.6 | .4 | 65.4 | 3.1 | 26.9 | .7 | .8 |
| 87A | .356 | 584 | 579 | 2,990 | 330 | 1.6 | 3.6 | .4 | 55.6 | 5.5 | 30.8 | 1.3 | 1.2 |
| 87B | .351 | 580 | 575 | 3,020 | 280 | 1.4 | 3.6 | .5 | 56.0 | 5.4 | 30.3 | 1.3 | 1.5 |
| 88 | .364 | 592 | 581 | 2,990 | 290 | 2.1 | 4.0 | .4 | 53.7 | 6.2 | 32.7 | .2 | .7 |
| 88A | .350 | 570 | 576 | 2,880 | 260 | 1.9 | 3.9 | .4 | 55.2 | 5.2 | 31.9 | .3 | 1.2 |
| 88B | .347 | 575 | 573 | 2,860 | 240 | 1.6 | 3.9 | .3 | 56.8 | 4.8 | 29.9 | 1.1 | 1.6 |
| 89 | .301 | 528 | 529 | 2,490 | 320 | 1.4 | 2.3 | .4 | 63.3 | 3.5 | 27.5 | .4 | 1.2 |
| 89A | .363 | 590 | 586 | 2,990 | 350 | 1.9 | 4.0 | .3 | 54.5 | 5.5 | 31.8 | .9 | 1.1 |
| 89B | .353 | 581 | 579 | 2,950 | 350 | 1.7 | 3.7 | .4 | 55.5 | 5.4 | 31.2 | 1.0 | 1.1 |
| 228 | .438 | 649 | 627 | 3,650 | 670 | 3.6 | 6.3 | .4 | 45.3 | 8.2 | 33.5 | 1.5 | 1.2 |
| 228A[2] | .431 | 626 | 613 | 3,470 | 590 | 3.4 | 5.9 | .3 | 47.4 | 7.8 | 32.9 | 1.1 | 1.2 |
| 228B[2] | .440 | 622 | 618 | 3,470 | 590 | 3.7 | 5.8 | .3 | 46.0 | 8.1 | 32.7 | 1.8 | 1.6 |
| 229[2] | .447 | 607 | 598 | 3,480 | 520 | 4.4 | 5.6 | .4 | 46.0 | 9.6 | 31.9 | 1.0 | 1.1 |
| 229A | .430 | 605 | 589 | 3,420 | 470 | 4.0 | 4.8 | .4 | 48.1 | 10.1 | 29.1 | 2.3 | 1.2 |
| 229B | - | - | - | - | - | - | - | - | - | - | - | - | - |

1/ Stripped of light oil and saturated with water vapor at 60° F. and under a pressure of 30 inches of mercury.
2/ Coal crushed to minus 1/8-inch.



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TABLE 10. - Physical properties of coke (BM-AGA method)

Coal a87-100 percent Hill bed (unwashed)
Coal 87-100 percent Hill bed (washed)
Coal 87A-20 percent Hill bed (washed) and 80 percent Pittsburgh bed
Coal 87B-30 percent Hill bed (washed) and 70 percent Pittsburgh bed
Coal 88-100 percent No. 5 Block bed
Coal 88A-80 percent No. 5 Block bed and 20 percent Pocahontas No. 3 bed
Coal 88B-70 percent No. 5 Block bed and 30 percent Pocahontas No. 3 bed
Coal 89-100 percent Pocahontas No. 6 bed
Coal 89A-20 percent Pocahontas No. 6 bed and 80 percent Pittsburgh bed
Coal 89B-30 percent Pocahontas No. 6 bed and 70 percent Pittsburgh bed

| Coal No. | True specific gravity | Apparent specific gravity | Cells, percent | Shatter test, cumulative percent upon- | | | | Tumbler test, cumulative percent upon- | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 2-inch screen | 1-1/2-inch screen | 1-inch screen | 1/4-inch screen | 2-inch screen | 1-1/2-inch screen | 1-inch screen | 1/4-inch screen |
| a87 | 1.90 | 0.82 | 56.9 | 60.5 | 81.4 | 95.1 | 98.4 | 15.0 | 42.4 | 66.4 | 74.6 |
| 87 | 1.86 | .82 | 55.9 | 56.6 | 81.7 | 96.6 | 98.9 | 12.6 | 45.0 | 70.9 | 77.3 |
| 87A | 1.89 | .85 | 55.0 | 47.4 | 79.9 | 94.6 | 98.5 | 3.0 | 32.9 | 64.6 | 74.8 |
| 87B | 1.88 | .85 | 54.8 | 40.5 | 77.1 | 94.9 | 99.0 | 3.7 | 30.2 | 65.5 | 76.8 |
| 88 | 1.96 | .89 | 54.6 | 49.5 | 74.0 | 89.3 | 97.6 | 1.5 | 18.9 | 46.8 | 66.7 |
| 88A | 1.90 | .89 | 53.2 | 56.1 | 79.5 | 92.2 | 98.1 | 4.7 | 25.6 | 53.3 | 71.1 |
| 88B | 1.91 | .89 | 53.4 | 65.8 | 83.1 | 93.4 | 98.3 | 6.7 | 31.0 | 55.7 | 71.6 |
| 89 | 1.93 | .94 | 51.3 | 80.7 | 91.0 | 95.2 | 98.4 | 19.1 | 44.6 | 56.4 | 65.8 |
| 89A | 1.92 | .88 | 54.2 | 47.9 | 77.6 | 92.7 | 97.9 | 3.9 | 24.0 | 56.2 | 70.8 |
| 89B | 1.91 | .88 | 53.9 | 57.7 | 81.1 | 93.6 | 97.9 | 6.5 | 30.6 | 56.1 | 70.1 |



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TABLE 11. - Physical properties of coke (Columbia Steel Co. methods)

Coal 228-100 percent Schwager composite
Coal 228A-90 percent Schwager composite (228) and 10 percent Pocahontas No. 3 bed
Coal 228B-90 percent Schwager composite (228) and 10 percent char
Coal 229-100 percent Lota composite
Coal 229A-90 percent Lota composite (229) and 10 percent Pocahontas No. 3 bed
Coal 229B-90 percent Lota composite (229) and 10 percent char

| Coal No. | True specific gravity | Apparent specific gravity | Cells percent | Shatter test, cumulative percent upon- | | | | Tumbler test, cumulative percent upon- | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 1-1/2-inch screen | 1-inch screen | 3/4-inch screen | 1/2-inch screen | 1-1/2-inch screen | 1-inch screen | 3/4-inch screen | 1/2-inch screen |
| 228 | 1.94 | 0.72 | 62.9 | 30 | 55 | 67 | 84 | 5 | 24 | 36 | 57 |
| 228A 1/ | 1.93 | .77 | 60.1 | 51 | 76 | 84 | 92 | 18 | 49 | 59 | 71 |
| 228B 1/ | 1.92 | .77 | 59.9 | 33 | 62 | 73 | 86 | 7 | 30 | 42 | 60 |
| 229 1/ | 1.94 | .75 | 61.4 | 36 | 67 | 75 | 86 | 4 | 33 | 45 | 58 |
| 229A | 1.95 | .78 | 60.0 | 48 | 79 | 87 | 93 | 14 | 55 | 64 | 72 |
| 229B | 1.94 | .76 | 60.8 | 34 | 65 | 75 | 87 | 5 | 35 | 46 | 58 |

1/ Coal crushed to minus 1/8-inch.



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The cokes from Chilean coals were tested by methods developed by the Columbia Steel Co. for testing cokes made from Utah coals. These methods are less severe than BM-AGA methods. Results for both the shatter and tumbler tests generally are higher for Lota coke, indicating that it forms a stronger coke than Schwager coal, either singly or in blends with 10 percent Pocahontas No. 3 coal or with 10 percent low-temperature char. The average shatter and tumbler indexes for 900° C. cokes from three samples of Lower Sunnyside bed coal from the Columbia mine were, respectively, as follows: 1-1/2-inch, 30 and 6; 1-inch, 69 and 46; 3/4-inch, 82 and 65; and 1/2-inch, 93 and 78. Lota and Schwager coals, therefore, yielded weaker coke than was obtained from Lower Sunnyside coal when carbonized under identical conditions. Blending either of these Chilean coals with 10 percent Pocahontas No. 3 coal improved the physical properties of their cokes enough to make them somewhat stronger than the Sunnyside coke. The low-temperature char, which was made from Schwager coal, improved Schwager coke but had virtually no effect when blended in this same proportion (10 percent) on the strength of Lota coke.

Table 12 shows the analysis of the tar and light oil. The properties of the tars generally are normal for the carbonizing temperature and ranks of coal tested. The tar distillates from the Chilean coals contained higher proportions of neutral oils. Similar results were obtained from tests of Lower Sunnyside coal, which is of similar rank. The composition of light oil from Hill coal differed markedly from that of the light oils from the other coals, including Pocahontas No. 6, which is of similar rank. Hill coal light oil (from the washed sample) contained 53.3 percent benzene, whereas all others contained more than 70 percent. The proportions of the other three constituents, toluene, paraffins, and solvent naphtha, were higher in Hill coal light oil; this difference was especially large for solvent naphtha. However, Hill coal is not exceptional in this respect because other medium-volatile coals have yielded light oils low in benzene. The percentage composition of the 900° C. light oil from medium-volatile Bakerstown coal, for example, was benzene, 59.9; toluene, 24.6; paraffins, 4.0; and solvent naphtha, 11.5 percent.



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TABLE 12. - Analysis of tar distillate and light oil

Coal a87-100 percent Hill bed (unwashed)
Coal 87-100 percent Hill bed (washed)
Coal 87A-20 percent Hill bed (washed) and 80 percent Pittsburgh bed
Coal 87B-30 percent Hill bed (washed) and 70 percent Pittsburgh bed
Coal 88-100 percent No. 5 Block bed
Coal 88A-80 percent No. 5 Block bed and 20 percent Pocahontas No. 3 bed
Coal 88B-70 percent No. 5 Block bed and 30 percent Pocahontas No. 3 bed
Coal 89-100 percent Pocahontas No. 6 bed
Coal 89A-20 percent Pocahontas No. 6 bed and 80 percent Pittsburgh bed
Coal 89B-30 percent Pocahontas No. 6 bed and 70 percent Pittsburgh bed
Coal 228-100 percent Schwager composite
Coal 228A-90 percent Schwager composite (228) and 10 percent Pocahontas No. 3 bed
Coal 228B-90 percent Schwager composite (228) and 10 percent char
Coal 229-100 percent Lota composite
Coal 229A-90 percent Lota composite (229) and 10 percent Pocahontas No. 3 bed
Coal 229B-90 percent Lota composite (229) and 10 percent char

| Coal No. | Distillate, percent by volume of dry tar | | | Neutral tar oil, percent by volume | | | Refined light oil from gas, percent by volume | | | | Olefins in crude light oil from gas, percent by volume |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Acids | Bases | Neutral oils | Olefins | Aromatics | Paraffins and naphthenes | Benzene | Toluene | Paraffins | Solvent naphtha | |
| a87 | 4.3 | 0.8 | 25.4 | 7.4 | 87.0 | 5.6 | 51.8 | 23.4 | 7.4 | 17.4 | 13.4 |
| 87 | 4.9 | 1.0 | 24.1 | 5.7 | 88.8 | 5.5 | 53.3 | 23.6 | 7.6 | 15.5 | 12.0 |
| 87A | 8.1 | 1.7 | 32.5 | 9.8 | 83.9 | 6.3 | 61.0 | 20.0 | 9.8 | 9.2 | 14.3 |
| 87B | 7.1 | 1.8 | 30.5 | 9.5 | 85.7 | 4.8 | 66.4 | 18.9 | 7.9 | 6.8 | 13.6 |
| 88 | 3.7 | 1.8 | 25.4 | 10.3 | 87.9 | 1.8 | 77.6 | 15.6 | 4.0 | 2.8 | 10.4 |
| 88A | 3.2 | 1.6 | 23.2 | 9.4 | 89.1 | 1.5 | 76.3 | 17.9 | 2.8 | 3.0 | 9.5 |
| 88B | 4.6 | 2.1 | 26.1 | 10.2 | 87.8 | 2.0 | 70.4 | 20.7 | 3.9 | 5.0 | 11.2 |
| 89 | 1.1 | 1.0 | 15.7 | 10.7 | 88.9 | .4 | 75.1 | 19.2 | 1.5 | 4.2 | 8.3 |
| 89A | 5.0 | 1.9 | 27.4 | 14.7 | 83.0 | 2.3 | 74.5 | 16.6 | 5.0 | 3.9 | 9.5 |
| 89B | 4.0 | 1.8 | 27.5 | 10.1 | 87.4 | 2.5 | 73.5 | 16.7 | 5.6 | 4.2 | 10.0 |
| 228 | 5.1 | 2.5 | 35.7 | 11.0 | 87.0 | 2.0 | 70.4 | 22.9 | 3.6 | 3.1 | 13.6 |
| 228A[1] | 4.3 | 2.4 | 31.4 | 10.0 | 89.1 | .9 | 74.9 | 19.7 | 2.8 | 2.6 | 11.2 |
| 228B[1] | 4.8 | 2.3 | 32.5 | 12.0 | 86.7 | 1.3 | 74.9 | 18.5 | 4.0 | 2.6 | 11.0 |
| 229[1] | 4.8 | 2.7 | 32.5 | 14.0 | 84.9 | 1.1 | 76.7 | 19.4 | 1.8 | 2.1 | 12.2 |
| 229A | 4.6 | 2.4 | 32.0 | 13.0 | 86.6 | .4 | 74.2 | 20.6 | 2.2 | 3.0 | 10.8 |
| 229B | 4.4 | 2.6 | 32.3 | 12.0 | 87.6 | .4 | 75.5 | 19.4 | 2.5 | 2.6 | 10.4 |

1/ Coal crushed to minus 1/8-inch.

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A report giving results of a study on the carbonizing properties of low-volatile bituminous Pocahontas No. 3-bed coal and of its 20:80 and 30:70 blends with Pittsburgh-bed, Warden mine, coal was published.70/ The investigations of the Pocahontas No. 3 coal included chemical analyses, agglutinating and plasticity tests, BM-AGA carbonization tests at 500°, 600°, 700°, 800°, 900°, and 1,000° C., determinations of oxidizing and expanding properties, and high- and low-temperature assay distillation tests. Oxidized samples of the coal were carbonized at 800° C., and the two blends with Pittsburgh-bed coal at 900° C. The Pocahontas No. 3 coal sample contained 5.2 percent ash and 0.7 percent sulfur on the as-carbonized basis, which are well below the limits specified for the production of metallurgical coke. As was expected because of its high rank, the coal gave an agglutinating value of 10.9 at a silicon carbide:coal ratio of 15:1, showed a low maximum Gieseler plastometer fluidity value of 2.7 dial divisions per minute at 481° C., and expanded strongly during carbonization. Yields of carbonization products in the 18-inch BM-AGA retort at 900° C. were: coke, 82.8 percent; and, on the basis of a ton of coal - gas 10,500 cubic feet; tar, 3.5 gallons; light oil in gas, 1.32 gallons; and ammonium sulfate, 11.6 pounds. The average charge density was 49.6 pounds per cubic foot, and the time of carbonization was 11.8 hours. The coke was blocky, fine-grained, and stable; the 1-1/2-inch shatter index was 81.2, and the 1- and 1/4-inch tumbler indexes were 64.4 and 74.5, respectively. The gas had a specific gravity of 0.280 and a determined heating value of 504 B.t.u. per cubic foot; the heating value of the gas per pound of coal was 2,650 B.t.u. The content of hydrogen sulfide was 90 grains per 100 cubic feet of gas. Blending the Pocahontas No. 3-bed with 70 and 80 percent Pittsburgh-bed coal increased the charge density to 49.9 pounds per cubic foot and decreased the carbonizing at 900° C. to 10.8 hours. The blends yielded less coke and more byproducts than were obtained from 100 percent Pocahontas No. 3 coal. Oxidation in air at 99.3° C. for 2.1 and 4.1 days had little effect on the quality of coke produced at 800° C.; oxidation for 8.0 days lowered the 1- and 1/4-inch tumbler indexes but did not affect the 1-1/2-inch shatter index; oxidation for 16.1 days virtually destroyed the coking property. Pocahontas No. 3 coal expanded enough to deform the BM-AGA retorts at all carbonizing temperatures except 500° C. It expanded 18.9 percent in the sole-heated oven at a charge density of 53.0 pounds per cubic foot, which is equivalent to 24.4 percent expansion at the charge density of 55.5 pounds per cubic foot used as a standard for comparison purposes.

A paper giving results of an investigation of the carbonizing properties and petrographic composition of Hazard No. 4 bed, Columbus No. 4 mine, Allais, Perry County, Ky., and of the high-temperature properties of Hazard No. 7 bed, Hardburly mine, Hardburly, Perry and Knott Counties, Ky., was published.71/ The high-volatile A bituminous Hazard No. 4 coal was carbonized

70/ Davis, J. D., Reynolds, D. A., Ode, W. H., and Holmes, C. R., Carbonizing Properties of Pocahontas No. 3-Bed Coal from Kimball, McDowell County, W. Va., and the Effect of Blending This Coal with Pittsburgh-Bed Coal: Bureau of Mines Tech. Paper 670, 1944, 35 pp.

71/ Davis, J. D., Reynolds, D. A., Ode, W. H., Holmes, C. R., Elder, J. L., and Wilson, J. E., Carbonizing Properties and Petrographic Composition of Hazard No. 4 Coal from Columbus No. 4 Mine, and High-Temperature Carbonizing Properties of Hazard No. 7 Coal from Hardburly Mine, Perry County, Ky.: Bureau of Mines Tech. Paper 672, 1945, 46 pp.



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by the BM-AGA method at 500°, 600°, 700°, 800°, 900°, and 1,000° C.; blends of this coal with 20 and 30 percent of low-volatile bituminous Pocahontas No. 3-bed coal at 900° C.; and the high-volatile A bituminous Hazard No. 7 coal at 900°C. The Hazard No. 4 bed was 33.0 to 42.25 inches thick at three points sampled in the Columbus No. 4 mine and contained no partings. The columnar sample examined microscopically contained 11 area percent of opaque attritus and 3 percent fusain; the coal, therefore, was classified as a bright coal. The carbonizing sample, taken at a representative point in the mine, contained 60.7 percent fixed carbon on the dry, mineral-matter-free basis and had a heating value of 14,440 B.t.u. per pound on the moist, mineral-matter-free basis. It contained 3.6 percent moisture, 3.8 percent ash, and 0.6 percent sulfur as carbonized. The ash softened at 2,400° F. The friability (12.9 percent by the A. S. T. M. tentative method) was low; the agglutinating index determined on a 15:1 mixture of silicon carbide and coal was 4.1. Plasticity tests indicated that Hazard No. 4 coal fuses at a relatively high temperature and has a short plastic range; the maximum fluidity in the Gieseler plastometer (10.6 dial divisions per minute) was low for a high-volatile A bituminous coal. Yields of carbonization products from Hazard No. 4 coal in the 18-inch retort at 900° C. were: coke, 66:8 percent, and, on the basis of per ton of coal carbonized - gas, 10,700 cubic feet; tar, 12.2 gallons; light oil in gas, 2.88 gallons; and ammonium sulfate, 23.4 pounds. The high-temperature cokes were highly fissured and therefore relatively weak; the 1-1/2-inch shatter and 1-inch tumbler indexes of the 900° C. cokes were satisfactory. Blending with 20 percent Pocahontas No. 3 coal greatly increased the size and strength of the 900° C. coke, but little was gained by increasing the proportion of Pocahontas No. 3 coal to 30 percent. The 900° C. gas had a heating value of 3,280 B.t.u. per pound of coal and contained 280 grains of hydrogen sulfide per 100 cubic feet. The Hazard No. 7 bed was 53.5 to 55.5 inches thick at five points in the Hardburly mine and was separated into two benches by a layer of bone 3 to 5 inches thick. Except for a higher ash content of 6.7 percent as compared to only 3.8 percent on the as-carbonized basis for the Hazard No. 4 coal, the chemical composition of the two coals checked closely. The agglutinating value, plastic properties, and yields of carbonization products of the two coals were similar. Hazard No. 7 coke was stronger than Hazard No. 4 coke. Both Hazard coals contracted during carbonization in the sole-heated, expansion-test oven. The percentage contraction at a charge density of 55.5 pounds per cubic foot was 3.2 for Hazard No. 4 coal and 9.5 for Hazard No. 7 coal. Oxidizing tests at 100° C. showed that Hazard No. 4 coal oxidizes at a high rate and that it would be almost three times as likely to heat spontaneously as Pittsburgh-bed, Warden mine, coal. The durability of coking power, defined as the time of oxidation in days in air at 100° C. required to reduce the coke-strength index 15 percent, was 3.93 days for Hazard No. 4 coal and 28.5 days for the Warden mine coal.

## Effect of Temperature and Rate of Heating on Carbonization Yields

A chapter[72] discussing the dependence of yields of products on temperature and rate of heating was contributed to a recent two-volume book on the

72/ Davis, J. D., Dependence of Yields of Products on Temperature and Rate of Heating: Nat. Research Council (H. H. Lowry, ed.), Chemistry of Coal Utilization, New York, vol. 1, 1945, pp. 834-847.



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chemistry of coal utilization. The dependence of carbonizing time on the width of the coke oven, methods of determining the rate of heating in coke ovens, the importance of the plastic stage of coal during carbonization, the effect of heating through the preplastic range, and Bureau of Mines work on effect of carbonizing temperature and rate of heating on yields of carbonization products were discussed. In industrial carbonization of coal it is virtually impossible to separate the effects of these two latter factors, because both factors change simultaneously. Both temperature and time of contact of the volatile products affect the extent of secondary decomposition of the so-called volatile carbonization products from coal; however, it appears that within the range of industrial carbonization conditions, at least, temperature is perhaps the more important.

## Durability of Coking Power of Various Coals

The Bureau of Mines test for deterioration of coking power requires exposure to air in a rotary drum at 99.3° C. of a large (400-pound) sample of coal stage-crushed 0- to 1/4-inch in size, followed by periodic carbonization tests involving determination of the quality of the coke on charges of approximately 100 pounds of the oxidized sample. The volume of oxygen used is determined from analyses of the gases as the oxidation progresses, but the significant figure reported is the time of oxidation in days required to reduce the strength of the coke by 15 percent. This time is designated as $T_{15}$ and and is an expression of "durability of coking power." The "durability of coking power" of BM-AGA coals tested during the year is given in table 13. The value for Pittsburgh-bed (Warden mine) coal is included for comparison. It is clear from these results that the coking power of Pittsburgh coal is extremely resistant to exposure in storage, that the No. 5 Block, Hill, and Pocahontas No. 6 coals are considerably less resistant, and that the Chilean coals can hardly be stored at all without loss of coking power.

TABLE 13. - Durability of coking power of coals

| Coal No. | Coal and source | Rank | Durability of coking power, $T_{15}$ days |
|---|---|---|---|
| 28 | Pittsburgh bed, Warden mine, Allegheny County, Pa..... | High-volatile A | 28.5 |
| 88 | No. 5 Block bed, No. 5 mine, Montcoal, Raleigh County, W. Va..... | do. | 10.2 |
| 87 | Hill bed, Hickey No. 1 mine, Cherokee County, Ala..... | Medium-volatile | 8.1 |
| 89 | Pocahontas No. 6 bed, Birdseye mine, Sewell, Fayette County, W. Va..... | do. | 5.7 |
| 228 | Composite Schwager area coal from near Santiago, Chile..... | High-volatile A | 1/ .0 |
| 229 | Composite Lota area coal from near Santiago, Chile..... | do. | 1/ .0 |

1/ Oxidation for 1 day virtually destroyed the coking power; there remained insufficient fused coal for test.



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## Plasticity of Coals

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Plastic properties of the 74 coal samples and blends described in table 14 were determined during the fiscal year. The samples were tested by either the Gieseler and/or Davis plastometer methods; two or more tests on the same sample were usually made by each method. A total of 296 tests - 162 by the Gieseler method and 134 by the Davis plastometer method - were made.

TABLE 14. - Description of coals and blends tested

| Coal No. | Description |
|---|---|
| 87 | Hill bed, Hickey mine, Fort Payne, Cherokee County, Ala. (washed) |
| 87A | 20 percent coal 87 and 80 percent Pittsburgh bed, Warden mine, coal 28 (washed) |
| 87B | 30 percent coal 87 and 70 percent coal 28 |
| 28 | Pittsburgh bed, Warden mine, Allegheny County, Pa. (washed) |
| a87 | Hill bed, Hickey mine, Fort Payne, Cherokee County, Ala. (unwashed) |
| 89 | Pocahontas No. 6 bed, Birdseye mine, Sewell, Fayette County, W. Va. |
| 89A | 20 percent coal 89 and 80 percent coal 28 |
| 89B | 30 percent coal 89 and 70 percent coal 28 |
| 89 | Coal 89 oxidized 7.35 days in air at 99.5° C. |
| 75 | Pocahontas No. 3 bed, Kimball, McDowell County, W. Va. |
| 75A | 20 percent coal 75 and 80 percent coal |
| 204A | 80 percent coal 28, 17 percent coal 75, and 3 percent Buckwheat No. 5-size anthracite |
| 204B | 80 percent coal 28, 15 percent coal 75, and 5 percent Buckwheat No. 5-size anthracite. |
| 205C | 80 percent coal 28, 13 percent coal 75, and 7 percent Buckwheat No. 5-size anthracite |
| | Coals from Chile, South America |
| 216 | Lota mine, sample from Pennsylvania State College, State College, Pa. |
| 216A | 90 percent coal 216 and 10 percent coal 75 |
| 216B | 80 percent coal 216 and 20 percent coal 75 |
| 216C | 80 percent coal 216 and 20 percent coal 80, Stigler bed, Garland mine, Okla. |
| a216 | Lota mine, sample from New York City |
| 218 | Schwager mine, sample from Pennsylvania State College, State College, Pa. |
| 218A | 90 percent coal 218 and 10 percent coal 75 |
| 218B | 80 percent coal 218 and 20 percent coal 75 |
| a218 | Schwager mine, sample from New York City |
| 219 | Josefina mine |
| 220 | Pupunahue mine |
| 221 | Elena mine |
| a228 | No. 3 bed, San Jose mine, Schwager mining area, Chile |
| b228 | No. 5 bed, San Pedro Sur mine, Schwager mining area, Chile |
| 228 | 50 percent coal a228 and 50 percent coal b228 |
| 228A | 90 percent of 50:50 composite (coal 228) and 10 percent coal 75 |
| b228A | 90 percent coal b228 and 10 percent coal 75 |
| a229 | Alta bed, Pique Nuevo mine, Lota mining area, corresponds to Schwager No. 5 bed |
| b229 | Alta bed, Piquo Grande mine, Lota mining area, corresponds to Schwager No. 5 bed |



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TABLE 14. - Description of coals and blends tested (cont'd.)

| Coal No. | Description |
|---|---|
| c229 | Chica bed, Pique Grande mine, Lota mining area, corresponds to Schwager No. 4 bed. |
| d229 | Arriba bed, Pique Grande mine, Lota mining area, corresponds to Schwager No. 3 bed |
| 229 | Composite of Lota coals: 5 percent coal a229, 45 percent coal b229, 25 percent coal c229, and 25 percent coal d229 |
| 229A | 90 percent coal 229 (4.5 percent coal a229, 40.5 percent coal b229, 22.5 percent coal c 229, and 22.5 percent coal d229) and 10 percent coal 75 |
| 229B | 90 percent coal 229 (4.5 percent coal a229, 40.5 percent coal b229, 22.5 percent coal c229, and 22.5 percent coal d229) and 10 percent char made from coal b228 |
| c229A | 90 percent coal c229 and 10 percent coal 75 |
| c229B | 90 percent coal c229 and 10 percent char made from coal b228 |
| 229 | Coal 229 oxidized 1.10 days in air at 99.3° C. |
| | Special samples |
| 88 | No. 5 Block (Lower Kittanning) bed, No. 5 mine, Raleigh Co., W. Va. |
| | Layer 5 - 167 mm. thick; 15.06" to 21.63" from base of bed |
| | Layer 6 - 126 mm. thick; 21.63" to 26.59" from base of bed |
| | Layer 12 - 46 mm. thick; 43.29" to 45.10" from base of bed |
| | Layer 16 - 110 mm. thick; 51.80" to 56.13" from base of bed |
| | Layer 17 - 61 mm. thick; 56.13" to 58.53" from base of bed |
| - | Michigan spore coal, Williamston, Mich. |
| XP-59 | Pittsburgh bed, No. 20 mine, Pa. |
| 235 | Coke-oven mix from charging car, Cía Carbonifera de Sabinas, S. A., Rosita, Coahuila, Mexico |
| 238 | Powellton bed, Nos. 7 and 9 mines |
| 239 | Powellton bed, Powellton No. 3 mine |
| 240 | Pocahontas bed, General Coal Crozer mine |
| | Core-drill hole 5-33, Paonia, Gunnison County, Colo. sec. 33, T. 13 S., R. 90 W. |
| 201 | Depth 267 feet; coal 6 feet, 3 inches |
| 202 | Depth 296 feet; coal 1 foot, 8 inches |
| 205 | Depth 357 feet; coal 1 foot, 2 inches |
| 203 | Depth 395 feet; coal 16 feet, 2 inches |
| 207 | Depth 447 feet; coal 6 feet, 10 inches |
| 208 | Depth 459 feet; coal 4 feet, 11 inches |
| 210 | Depth 570 feet; coal 8 feet, 11 inches |
| 211 | Depth 583 feet; coal 11 inches |
| 212 | Depth 599 feet; coal 11 feet, 3 inches |
| 213 | Depth 653 feet; coal 3 feet, 8 inches |
| 214 | Depth 670 feet; coal 3 feet, 1 inch |



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TABLE 14. - Description of coking power of coals tested (cont'd.)

| Float-and-sink samples of Pittsburgh bed (Shannopin mine)coal, Greene County, Pa. | | |
|---|---|---|
| Fractions | Ash, percent | Sulfur, percent |
| Float 1.25 sp. gr. | 1.87 | 1.47 |
| 1.26 - 1.27 sp. gr. | 2.61 | 1.55 |
| 1.28 - 1.29 sp. gr. | 4.52 | 1.87 |
| 1.30 - 1.31 sp. gr. | 6.88 | 2.29 |
| 1.32 - 1.33 sp. gr. | 8.04 | 2.56 |
| 1.34 - 1.35 sp. gr. | 8.92 | 2.76 |
| 1.35 - 1.37 sp. gr. | 10.96 | 3.30 |
| 1.37 - 1.40 sp. gr. | 13.08 | 3.90 |
| 1.40 - 1.50 sp. gr. | 17.60 | 4.82 |
| 1.50 - 1.60 sp. gr. | 23.34 | 5.26 |

A problem of considerable importance to Alabama coke-oven operators is obtaining economically a nearby source of low- or medium-volatile bituminous coal suitable for blending with the high-volatile A bituminous coals that are now mined and coked in Alabama. Tests of the plastic properties of both washed and unwashed samples of Hill bed, Hickey mine, medium-volatile bituminous coal from Fort Payne, Cherokee County, Ala., indicated that this coal should be suitable for blending purposes. The main difference in plastic properties between the washed and unwashed samples was that the latter showed an intermittent resistance in the later stages of the plastic temperature range as determined in the Davis plastometer test. This resistance is probably due to the presence of hard ash particles. Plastic properties also were determined in 20:80 and 30:70 blends of the washed Hill-bed coal and Pittsburgh-bed, Warden mine, washed coal. The typical, high-volatile A bituminous Warden coal is used commercially in coke-oven charges and has been used generally as a standard blending coal in BM-AGA survey tests of American coals. The plastic properties of the two blends of Hill-bed and Pittsburgh-bed coals indicate that good coke can be expected from blends of Hill-bed coal and typical high-volatile A bituminous coals such as are mined in Alabama.

Plastic properties were determined on (1) a sample of medium-volatile bituminous, Pocahontas No. 6-bed (Birdseye mine) coal from Fayette County, W. Va.; (2) two blends of this coal with 80 and 70 parts, respectively, of Pittsburgh-bed (Warden mine) coal; and (3) the Pocahontas No. 6-bed coal after 7.35 days of oxidation in air at 99.3° C. The plastic properties of the Pocahontas coal were typical of higher-ranking, medium-volatile coals. The blends showed plastic properties that are characteristic of blends of medium-volatile and high-volatile A bituminous coals in the proportions named. Pocahontas No. 6-bed coal, after 7.35 days of oxidation, showed only slight fusion. Although not as desirable as low-volatile bituminous fusion. Although not as desirable as low-volatile bituminous Pocahontas No. 3-bed coal, the medium-volatile bituminous Pocahontas No. 6-bed coal appears to be suitable for blending with high-volatile A bituminous coal.



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Tests of the plastic properties of Pocahontas No. 3-bed coal from McDowell County, W. Va., indicated that this low-volatile coal should produce a good coke. Such strong resistance was developed in the Davis plastometer test that the limit of the springs was reached, indicating a maximum resistance of more than 29 pound-inches. The coke residue formed in both the Davis and Gieseler plastometer tests was very strongly swollen. Plastic properties of a blend containing 20 percent of this coal and 80 percent of Pittsburgh-bed (Warden bed) washed coal were typical of a blend containing these proportions of low- and high-volatile A bituminous coals. To determine the effect of substituting Buckwheat No. 5-size anthracite for a part of the low-volatile bituminous coal in coke-oven charges, three blends containing 80 percent high-volatile A bituminous coal, and low-volatile bituminous coal plus anthracite were prepared. The blends consisted of 80:17:3, 80:15:5, and 80:13:7 parts, respectively, of Pittsburgh-bed (Warden mine) coal, Pocahontas No. 3-bed coal, and Buckwheat No. 5-size anthracite. With increasing percentages of anthracite, the Gieseler maximum fluidity and the Davis maximum resistance values decreased somewhat, indicating that the resulting cokes would become progressively weaker and, if too much anthracite were substituted for the low-volatile bituminous coal, would be too weak for metallurgical use.

The properties of 24 high-volatile A bituminous coals and coal blends and 3 subbituminous B coals from 5 mining areas in Chile were determined. Gieseler and Davis plastometer tests made on two samples of high-volatile A bituminous coal from the Lota area and on blends of 80 and 90 percent of the Lota coal with 20 and 10 percent, respectively, of low-volatile bituminous coal from the Pocahontas No. 3 bed, McDowell County, W. Va. showed low fluidity and low resistance, and only slight fusion at the normal rate of heating of 3° C. per minute. The high-ranking, low-volatile bituminous West Virginia coal (dry, mineral-matter-free, fixed-carbon content, 81.7 percent) and the high-volatile A Chilean coal (dry, mineral-matter-free, fixed-carbon content, 53.8 percent) are too far apart in rank to permit good fusion. A third blending with 10 percent medium-volatile bituminous coal from the Stigler bed, Garland mine, Okla., proved somewhat better.

Plastic properties were determined on two samples of high-volatile A bituminous coal from the Schwager area. These samples were characterized by low maximum fluidities in the Gieseler tests and low intermittent resistance and slight fusion in the Davis tests. Blending this coal with 10 percent low-volatile bituminous coal from the Pocahontas No. 3 bed, caused no appreciable differences, but increasing the amount of low-volatile coal to 20 percent resulted in a considerable increase in maximum resistance as measured in the Davis plastometer.

Subbituminous B coals from the Josefina mine, the Pupunahue mine, and the Elena mine showed no fusion in the Gieseler tests at the normal rate of heating of 3° C. per minute.

Tests of plastic properties were completed on two high-volatile A bituminous coals from the Schwager mining area. The No. 3-bed (San Jose mine) coal showed a maximum fluidity in the Gieseler plastometer test of 295 dial



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divisions per minute, and a maximum resistance of 6.5 pound-inches and a fairly long plastic temperature range in the Davis plastometer test. The No. 5-bed (San Pedro Sur mine) coal showed only 9.2 dial divisions per minute in the Gieseler test and 9.5 pound-inches in the Davis test. These results indicate better coking properties for the No. 3-bed coal than for the No. 5-bed coal. Blending 90 percent of the No. 5-bed coal with 10 percent Pocahontas No. 3-bed coal lowered the maximum fluidity and maximum resistance somewhat and lengthened considerably the plastic temperature range in the Davis test. A composite sample consisting of 50 percent of the No. 3-bed coal and 50 percent of the No. 5-bed coal raised the maximum fluidity to 41 dial divisions per minute and lowered the maximum resistance to 2.1 pounds-inches. Blending 90 percent of this composite of high-volatile A bituminous coals with 10 percent low-volatile bituminous Pocahontas No. 3-bed coal increased the maximum resistance and lengthened considerably the plastic temperature range in the Davis test.

Plastic properties were determined in the Gieseler and Davis plastometers for four high-volatile A bituminous coals from the following beds and mines in the Lota mining area: Alta bed, Pique Nuevo mine; Alta bed, Pique Grande mine; Chica bed, Pique Grande mine; and Arriba bed, Pique Grande mine. In general, the plastic characteristics observed were high fusion temperatures, low maximum fluidities below 5.0 dial divisions per minute, and short plastic temperature ranges. The Chica-bed coal showed no fusion at the normal rate of heating of 3° C. per minute in the Davis test, and the Arriba-bed coal showed a slightly higher maximum fluidity and resistance than did the three other coals. Tests on a composite of the four coals consisting of 5 percent Alta bed (Pique Nuevo mine) coal, 45 percent Alta bed (Pique Grande mine) coal, 25 percent Chica bed (Pique Grande mine) coal, and 25 percent Arriba-bed (Pique Grande mine) coal, and on a blend of 90 percent of this composite with 10-percent low-volatile bituminous, Pocahontas No. 3-bed coal also showed plastic characteristics of poor fusion and low maximum fluidity and resistance. A second blend of 90 percent Lota composite and 10 percent char from the No. 5-bed (San Pedro Sur mine) coal in the Schwager mining area showed only slight fusion at the normal rate of heating of 3° C. per minute in the Davis tests. Oxidizing the composite of Lota coals reduced the maximum fluidity in the Gieseler tests and destroyed the fusion properties in the Davis tests. Blending 90 percent Chica-bed coal with 10 percent of low-volatile, Pocahontas No. 3-bed coal or with 10 percent of char made from the No. 5-bed (San Pedro Sur mine) coal from the Schwager mining area also resulted in slight fusion in the Davis tests.

Plastic properties were determined on No. 5 Block-(Lower Kittanning)-bed, No. 5 mine, coal from Raleigh County, West Virginia, and on five layer samples selected from the columnar section of this coal. The petrographic composition of the coal and the five layer samples had been determined in detail in the Bureau's petrographic laboratory. An attempt was made to correlate the plastic properties with the petrographic composition. In general, if the total anthraxylon and translucent attritus were present in large proportions, either separately or as the sum of the two, the fluidity of the samples was high. The presence of high opaque attritus content reduced the



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fluidity of the samples. There seems to be a general relationship also between the types of vitrain present, rather than its total amount, and the fluidity developed during plastometer tests. The fluidity was high in some of the samples containing but little vitrain and in all the samples containing appreciable vitrain.

Fusion properties were determined on a sample of cleaned spores which had been separated from a spore coal mined in the Williamston Basin, Mich. Duplicate tests in the Gieseler plastometer at a heating rate of 3° C. per minute showed sharp melting of the entire sample at 398° C. and 393° C., and a maximum fluidity of 60,000 dial divisions per minute at 401° C. The sharp fusion and the high fluidity of the sample immediately above the fusion temperature indicate that the spores are quite homogeneous in composition.

Plastic properties of five coals were determined in connection with studies of their expanding properties. These coals included: (1) Pittsburgh-bed, No. 20 mine, high-volatile A bituminous coal; (2) a medium-volatile bituminous coke-oven mix taken from the charging at Cía Carbonifera de Sabinas, S.A., Rosita, Coahuila, Mexico; (3) high-volatile A bituminous, Powellton-bed (Nos. 7 and 9 mines) coal; (4) high-volatile A bituminous, Powellton-bed (No. 3 mine) coal; and (5) low-volatile bituminous, Pocahontas-bed (General Crozer mine) coal. The Pittsburgh-bed coal showed good initial fusion properties but gave two pronounced high maximum resistance values of 26.0 and 40.5 pound-inches at 494° C. and 518° C., respectively, and an intermittent resistance above 578° C. These properties indicate that this coal is not as uniform in composition as many other Pittsburgh-bed coals that have been tested by the Bureau of Mines. The Mexican coal blend showed plastic properties typical of medium-volatile coal and therefore should produce a good coke. The Powellton-bed (Nos. 7 and 9 mines) coal contained 66.0 percent dry, mineral-matter-free, fixed carbon and was much less fluid than the Powellton-bed (No. 3 mine) coal which contained 62.7 percent dry, mineral-matter-free, fixed carbon. The former coal showed such strong swelling that the Gieseler plastometer test had to be discontinued at 441° C.; it produced an intermittent resistance in the Davis plastometer up to 580° C., at which temperature the test was discontinued. The Pocahontas-bed coal showed plastic properties typical of a coal of low-volatile bituminous rank.

The plastic properties were determined by either or both the Gieseler and the Davis plastometer test methods on 10 core-drill samples representing coal taken at various depths in sec. 33, T. 13 S., R. 90 W., Gunnison County, Colo. None of the 10 samples showed fusion at the normal rate of heating of 3° C. per minute used.

To determine the relation between plastic properties and the specific gravity of the sample, a study was made of the plastic properties of float-and-sink fractions from Pittsburgh-bed (Shannopin mine) coal, Greene County, Pa. As is known, in a series of float-and-sink samples the specific gravity increases with increased amounts of ash and sulfur. In general, the fluidity of the samples decreased as the ash and sulfur contents increased. There were some exceptions to this general trend, but quite likely the chemical composition is related to the petrographic composition in such a manner that both are reflected in the plastic characteristics.



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A detailed study was made of the chemical and petrographic compositions and the physical properties of 19 representative American bituminous coking coals in relation to the maximum fluidity of these coals as measured by the Gieseler plastometer test method.73/ The coals studied included 5 low-, 4 medium-, and 10 high-volatile A bituminous coals whose carbonizing properties had already been determined in the BM-AGA survey of American coals. Factors of chemical and petrographic compositions that were found to contribute toward increasing the fluidity of a coal above that expected from consideration of its rank alone are high contents of anthraxylon and translucent attritus and the presence of cannel coal. For coals of similar rank, those of the higher physical strength, as measured by friability tests and the data of screen analyses, generally show higher maximum fluidity. Factors that reduce the fluidity of a coal below that expected from its rank are high oxygen, high ash, and other materials, such as opaque attritus and fusain, that are stable toward heat. The type and amount of petrographic constituents present is much more important than the rank of the coal in determining the fusion properties of bituminous coking coals.

A chapter 74/ describing the plastic, agglutinating, agglomerating, and swelling properties of coals was contributed to a recent two-volume book on the chemistry of coal utilization. The chapter includes a classification of the different methods of test, a summary of published investigations, an evaluation of test data in relation to commercial coke-oven practices, suggested desirable problems for further research, and a comprehensive bibliography of selected world literature dealing with these subjects.

## Swelling Properties of Coal During the Coking Process

Bureau of Mines testing equipment now available includes two vertical-slot ovens - one holding a charge of 350 pounds and one a cahrge of 17 pounds - also the sole-heated expansion oven described in previous reports. The vertical-slot ovens are heated from both walls and operate at constant volume; the pressure exerted by the expanding coal is measured during the tests. The sole-heated oven is heated only at the floor and is operated under a constant pressure of 2.2 pounds per square inch; the percent expansion (or contraction) obtained under these conditions is taken as the characteristic expansion index of the coal. The sole-heated oven is charged with 40 pounds of coal; test results are of value in indicating contraction and for rough comparison of expanding properties of different coals. The two vertical-slot ovens give the maximum pressure to be expected on coke-oven walls; this figure is of much more practical importance than percentage of expansion under constant load. The small vertical-slot oven is more convenient to use than the large one because of the smaller charge and shorter operating time. However, it gives

73/ Brewer, R. E., Plastic Characteristics of Coal. Correlation with Chemical and Physical Properties and Petrographic Composition: Ind. Eng. Chem., vol. 36, 1944, pp. 1165-1168.

74/ Brewer, R. E., Plastic, Agglutinating, Agglomerating, and Swelling Properties of Coals: Nat. Research Council (H. H. Lowry, ed.), Chemistry of Coal Utilization, New York, vol. 1, 1945, pp. 160-309.



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high maximum pressures because of the thinner layer of coke, the normal contraction of which counteracts the expansion of the charge while plastic. The pressure values divided by 2 closely approximate those obtained in the large slot oven.

Table 15 gives the expanding properties of BM-AGA coals and of special coals submitted by coke-oven operators tested during the year; the test oven used is indicated in each case. Medium-valatile bituminous Hill-bed coal in 100-percent charges expanded moderately. The blend with 80 percent Pittsburgh standard high-volatile A bituminous coal contracted slightly in the sole-heated oven and did not exert dangerous pressures in the large vertical slot oven. The blend of 20 percent Pocahontas No. 3 low-volatile coal and 80 percent high-volatile Pittsburgh coal exerted about the same maximum pressure in the large vertical-slot oven and about 1.7 times that maximum in the small vertical-slot oven. This blend is widely used in ovens making metallurgical coke; therefore, it may be concluded that the Hill coal should be perfectly safe when substituted in this proportion for Pocahontas No. 3 coal. No. 5 Block-bed coal contracted to about the same extent as Pittsburgh coal and, therefore, should be a good high-volatile blending coal, so far as expansion is concerned. Pocahontas No. 6 coal, although of medium-volatile rank, hardly expanded at all, but the raw coal had an ash content of 13.9 percent. The float coal on a 1.50-gravity solution contained 8.6 percent ash and expanded 7.4 percent, which is not excessive for coals of this rank. The effect of ash reduction on expansion is clearly indicated.

In testing the coals proposed by the Rochester Gas & Electric Co., it was desired to distinguish between the expanding properties of the two Freeport coals and to determine which of the three Pittsburgh coals was the most contracting. The tests indicated that the Indiana County Freeport coal expanded the least and the Banning Pittsburgh coal contracted the most. It was concluded, therefore, that blends of these two coals are likely to be safer to use than blends of the other Freeport coal with either of the other two Pittsburgh coals. From experience of the Bureau of Mines, such a conclusion is usually justified.

The blends of Powellton coals with Crozer Pocahontas were submitted in connection with development of new sources of supply for the synthetic ammonia works at Belle, W. Va. It was desired to know if any of them would prove dangerously expanding; results of the tests indicated that they are not.

The Rosita coal from Mexico showed contraction and should give no trouble in coke-oven operation.

The coals from the Chilean Schwager mining area are contracting; the No. 3 bed contracted more than the No. 5 bed. It is desired to use these coals unblended in coke ovens; test results show such practice to be perfectly safe.



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TABLE 15. - Expanding properties of coals

| Coal | Sole-heated oven | Vertical-slot ovens | |
|---|---|---|---|
| | Expansion, percent at 55.5 pounds per cu. ft. | Maximum pressure, pounds per square inch | |
| | | 350-pound vertical slot oven | 17-pound vertical slot oven |
| **BM-AGA coals** | | | |
| Hill bed (coal 87), Hickey No. 1 mine, Cherokee County, Ala. | | | |
| Washed | +20.3 | | |
| Unwashed | +14.8 | | |
| 20 percent Hill bed and 80 percent Pittsburgh bed (coal 28), Warden mine | - 1.5 | 1.69 | |
| 20 percent Pocahontas No. 3 bed (coal 75) and 80 percent Pittsburgh bed | - | 1.49 | 2.54 |
| No. 5 Block bed (coal 88), No. 5 Block mine, Raleigh County, W. Va. | -17.3 | | |
| Pocahontas No. 6 bed (coal 89), Birdseye mine, Preston County, W. Va. | + .2 | | +4.9 |
| Float on 1.50 gravity | + 7.4 | | |
| **Coals proposed by Rochester Gas and Electric Co.** | | | |
| Upper Freeport bed, Burke No. 1 mine, Preston County, W. Va. | + 9.2 | | |
| Lower & Upper Freeport beds, Kent Nos. 1 and 2 mines, Indiana County, Pa. | + 3.0 | | |
| Pittsburgh bed, Banning No. 1 mine, Westmoreland County, Pa. | -23.1 | | |
| Pittsburgh bed, Jamison No. 20 mine, Westmoreland County, Pa. | -17.7 | | |
| Pittsburgh bed, Warden mine, Allegheny County, Pa. | -15.6 | | |
| **Coals proposed for DuPont Ammonia Works, Belle, W. Va.** | | | |
| 50 percent Carbon Fuel Powellton and 50 percent Koppers Powellton (100 percent through 1/4-inch) | -26.3 | None | |
| 50 percent Carbon Fuel Powellton and 50 percent Koppers Powellton (100 percent through 1/8-inch) | - | None | |
| 20 percent Crozer Pocahontas, 40 percent Carbon Fuel Powellton, and 40 percent Koppers Powellton | -14.2 | + 1.3 | |
| 35 percent each of Koppers and Carbon Fuel Powellton and 30 percent Crozer Pocahontas | - 9.7 | + 1.9 | |
| **Miscellaneous coals** | | | |
| Rosita mine, Coahuila, Mexico | -12.7 | + 1.2 | |
| No. 3 bed, San Jose mine, Schwager district, Santiago, Chile | -15.1 | | |
| No. 5 bed, San Pedro mine, Schwager district, Santiago, Chile | - 9.6 | | |



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## Use of Anthracite in Coke-Oven Mixes

A study was made of the effects on quality of coke produced from coke-oven mixes in which a part of the low-volatile bituminous coal, or, in a few instances, a part of the high-volatile bituminous coal was replaced by anthracite fines. Results of research study and of operating experiences at 21 byproduct plants producing blast furnace, foundry, and domestic cokes were published.75/ Several plants reported increased production of foundry coke by use of anthracite fines. Of the 21 plants, favorable results were reported in 10 plants, neutral or indeterminate results in 7, and unfavorable results in 4. At the time the report was prepared, 4 plants were using anthracite fines in regular production of blast-furnace coke, and 5 in regular production of foundry coke. Study of test data and of operating experiences indicated that the effects of additions of anthracite fines to coking mixtures vary considerably with the nature of the bituminous coals used and the operating conditions at the plant. In general, a larger, blockier coke was produced that showed a better shatter index (percent of coke retained on a 2-inch screen after the A.S.T.M. drop shatter test) and a poorer hardness index (cumulative percent of coke on a 1/4-inch screen after the A.S.T.M. tumbler test). A few plants successfully used 4 to 5 percent of anthracite fines in their mixes for making blast-furnace coke, and it is indicated that many plants can substitute 3 to 5 percent of anthracite fines for the same percentage of low-volatile Pocahontas coal without any serious effects on blast-furnace operation. Thus far, it appears that low-volatile anthracite is preferable to high-volatile; this observation needs further study. The effect of the addition of anthracite may vary with the rank, field, or bed of all the coals used in the coke-oven mix. Preliminary tests of various mixtures are of considerable value in determining the best combination of coals. Probably the best procedure is to start with the lowest practical percentage of anthracite fines and gradually increase this, making such changes in the percentages of high- and low-volatile bituminous coals as the test results indicate desirable.

## Control of Bulk Densities of Coke-Oven Charges

Studies were made on the control of bulk density of the coke-oven charge and results of detailed studies of the coals used at three byproduct-coke plants were published.76/ This report summarizes operating difficulties traceable to fluctuations in moisture content of the coal and describes methods of measuring bulk density. The A.S.T.M. standard method of test usually employed for this measurement yielded lower results than those actually acountered in coke ovens. A modified method, called the dropped-coal method, was developed which gave results that agreed with the average

75/ Seymour, Wm., and Schmidt, L. D., Utilization of Anthracite Fines in the Manufacture of Byproduct Coke: Bureau of Mines Rept. of Investigations 3808, 1945, 23 pp. See also footnote reference 66.

76/ Landers, W. S., Schmidt, L. D., and Seymour, Wm., Control of Bulk Densities in Coke Ovens: Studies on Coal Used at Three Byproduct-Coke Plants: Bureau of Mines Rept. of Investigations 3807, 1945, 22 pp.



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density of the coal in the coke oven as calculated from the weight of charge and oven volume. Comparison of bulk-density measurements were made on the coal before and after treatment with 0.2 to 0.5 gallon of oil per ton of coal. The major effects of the addition of oil to the coal charge were: (1) Reduction of the fluctuations in bulk density with changes in the moisture content of the coal; (2) significant reduction in range of bulk density in a given coke oven; (3) increase in bulk density, except for coal of low moisture content; (4) reduction of the excessively high and dangerous bulk density for coal at low moisture content; and (5) lowering the angle of repose of the coal, except at very low moisture contents. The benefits of uniform bulk density of the coal charged to coke ovens are immediately evident through smoother plant operation and more uniform coke. Wartime needs for maximum production of uniform-quality coke and the inability of coke-oven operators to obtain regularly coal of desired purity have emphasized the immense value of careful bulk density control. Increased production of coke from existing coke ovens and avoidance of dangerous expanding pressures due to excessively high bulk densities have been the direct result of application of these Bureau of Mines studies.

## Coke for Western Steel Production

The second most important, if not indeed the outstanding, raw material for making pig iron and steel is coal. Deficiencies in western coking coals for the production of high-quality blast-furnace coke and lack of markets for coke-oven byproducts have always been serious handicaps to technical progress in steel production in the West. A report discussing the problems incident to production of steel in western steel plants was issued.77/ During the period 1890-1940 the population of the 11 Western States (Arizona, California, Colorado, Idaho, Montana, New Mexico, Nevada, Oregon, Utah, Washington, and Wyoming) increased nearly 240 percent, whereas that of the other 37 States rose only 64 percent. Accompanying this rapid gain in population was an increase in steel production and consumption in the Western States. Because the war has added considerably both to population from increased migration of war workers to the West and to western steel-production capacity, the question as to the outlook for continued use of the expanded capacity in the postwar years becomes of urgent importance. Before the war the West had plants capable of producing 2,109,000 net tons of ingot steel per year and afforded a market for steel products equivalent to approximately 3,500,000 tons of ingots, a substantial part of which was supplied by plants in the Central and Eastern States. War expansion increased production capacity to 4,655,000 tons. Postwar operations of the new plants will depend upon the attainment of several objectives that involve serious problems in recapitalization, marketing, type of steel products, adjustments in freight-rate structure, and technical progress in supply and improvement of raw materials. Careful analysis of the various factors involved indicates that the problems, while serious, are not insurmountable barriers to postwar operation of the new western steel plants at a reasonably

77/ Bain, H. F., A Pattern for Western Steel Production: Bureau of Mines Inf. Circ. 7315, 1945, 35 pp.; Western Steel Problems. Present Installations Not Viewed as Postwar White Elephants: Min. and Met., vol. 26, 1945, pp. 329-330.



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satisfactory rate. The technical aspects of western steel-plant operation are thoroughly considered. Progress in the improvement of coals from Colorado, Utah, and Washington for coke manufacture before and during the war, and suggestions for postwar consideration are discussed in detail.

## Control of Combustion in Beehive-Coke Ovens

As a result of technical studies by Bureau engineers on the control of combustion in beehive-coke ovens, the "burning" of coal in these ovens has been changed from an art to a science. This new information enables operators with a moderate amount of technical training to determine by means of a few simple analytical tests and appropriate calculations whether a beehive oven is getting too little or too much air and whether the coal is being consumed by burning or is being properly coked. If rapid expansion of the beehive-coking industry should ever again become necessary, there now need be no fear that the art of "burning" beehive ovens would be lost. A recent paper covering this information and other salient findings was published.78/ Technical surveys and assistance and demonstrations of scientific control were continued at beehive plants during the year, although to a decreasing extent as the production of beehive coke declined. One plant, which has been in continuous operation for more than 50 years, has started a long-range improvement program based on the findings and recommendations of Bureau of Mines engineers.

## Low-Temperature Carbonization of Alaskan Coals

Increasing demand in Alaska for liquid fuels and lubircants for both war and industrial purposes aroused concern regarding the supply of petroleum products. A general survey of the physical and chemical properties of 14 representative Alaskan coals was conducted to ascertain their potential use as a source of liquid fuel that might supplement present imports of petroleum products.79/ These 14 coals came from 5 mines and one prospect in 4 districts. The location, nature of floor and roof, and partings of the coal beds are given for each of the mines. The 14 samples included 1 high-volatile A bituminous coal and 1 high-volatile B bituminous coal from the Matanuska district; 1 subbituminous B coal from the Broad Pass district; 1 subbituminous C coal from the Fortymile district; and 6 subbituminous B coals and 4 subbituminous C coals from the Nenana district. Yields of carbonization products on the as-received basis, as obtained at 500° C. by the Bureau of Mines modified Fischer low-temperature assay, of the high-volatile A and B bituminous coals were (a) 68.8 and 72.7 percent of coke, (b) 40.9 and 28.8 gallons of tar and light oil per ton of coal, (c) 9 and 10 percent of water, and (d) 970 and 840 B.t.u. in gas per pound of coal, respectively. The 12 subbituminous coals tested yielded (a) 47.8 to 55.9 percent of char,

78/ Kelley, J. A., Manufacture of Beehive Coke: Proc. Blast Furnace and Raw Materials Committee, Am. Inst. Min. and Met. Eng., vol. 4, 1944, pp. 26-42; discussion, pp. 42-45.

79/ Selvig, W. A., Ode, W. H., and Davis, J. D., Low-temperature Carbonization of Alaskan Coals: Bureau of Mines Tech. Paper 668, 1944, 16 pp.



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(b) 9.7 to 37.3 gallons of tar and light oil per ton of coal, (c) 23.3 to 36.4 percent of water, and (d) 510 to 650 B.t.u. in gas per pound of coal. Of the subbituminous coals, the subbituminous B coal from the No. 6 bed, Old Suntrana mine, was second in importance to the high-volatile A bituminous, Eska mine, coal as a potential source of fuel oil; it yielded nearly as much tar and light oil - 37.3 compared to 40.9 gallons - but considerably less carbonized residue - 47.8 compared to 68.8 percent - and only 640 compared to 970 B.t.u. in gas per pound of coal.

A tipple sample of No. 4-bed coal from Suntrana mine was carbonized at 500° and 600° C. by the BM-AGA method, and yields and quality of carbonization products were determined. Data for a similar subbituminous coal from Weld County, Colo., obtained by the Bureau of Mines in 1939, were included for comparison. Yields, on the as-carbonized basis, of carbonization products of the Suntrana coal at 500° and 600° C., respectively, were (a) 48.8 and 44.8 percent of char, (b) 11.8 and 9.46 gallons of tar and light oil per ton of coal, (c) 32.7 and 32.3 percent of liquor, and (d) 910 and 1,440 B.t.u. in gas per pound of coal. The corresponding yields for the same products from the Colorado coal were (a) 56.7 and 51.8, (b) 11.1 and 8.75, (c) 30.3 and 29.1 and (d) 810 and 1,490. The yield of tar and light oil from the Suntrana coal was appreciably lower and that of B.t.u. in the gas considerably higher than corresponding values found by the Fischer assay tests on three samples from this same coal. These differences are due to the long time required for heating in batch in the BM-AGA retort at low temperatures which cause extensive cracking of the liquid products. Industrial methods which heat internally by the sensible heat in inert gases where the rate of heating is high are more practicable for large-scale production, and the liquids can then be removed before much cracking can take place.

## Gasification of Subbituminous Coal and Lignite

A small pilot plant was operated for about 1,000 hours at Golden, Colo., to study the technology of gasifying low-rank fuels in an externally-heated retort. A large pilot plant of the same general design was built at Grand Forks, N. Dak., and preliminary tests were made. The process was developed in connection with Bureau of Mines investigations on raw materials resources for steel production as a means to supply reducing gas for reduction of iron ore. A report of this investigation was prepared.80/

Figure 18 taken from this report shows the design of the small pilot plant. An alloy retort is suspended in a combustion chamber specially

80/ Parry, V. F., Gernes, D. C., Goodman, J. B., Wagner, E. O., Koth, A. W., Patty, W. L., and Yeager, E. C., Gasification of Lignite and Subbituminous Coal Progress Report for 1944 (I) Carbonization and Gasification of Lignite in Laboratory Retorts; (II) Gasification of Lignite in Glover-West Retorts; (III) Gasification of Lignite Char Briquets in a Water-Gas Machine; (IV) Gasification of Subbituminous Coal and Lignite in the Golden, Colo., Pilot Plant: Bureau of Mines Rept. of Investigations (in press).



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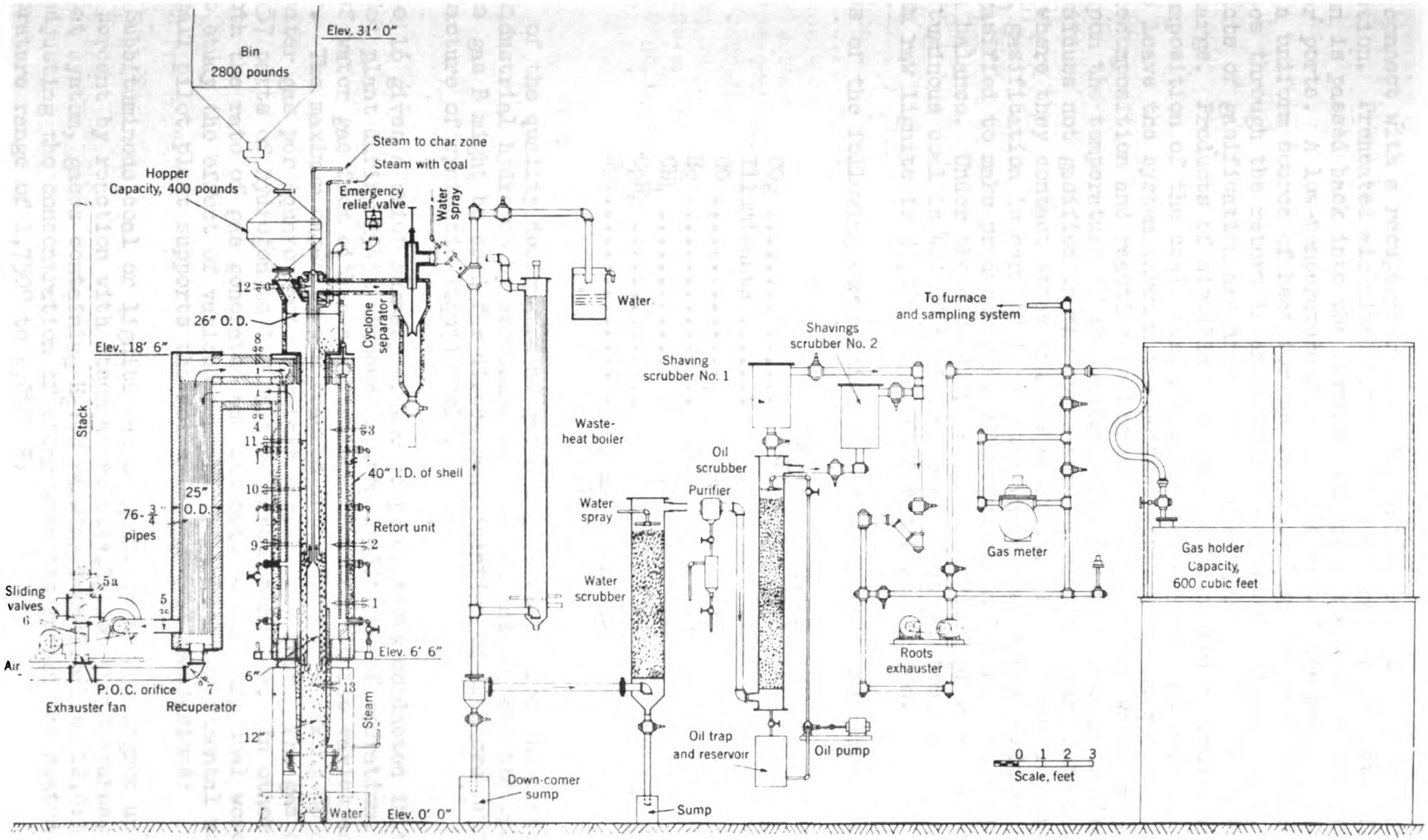


**Figure 18. - Pilot plant for complete gasification of coal, Parry retort, Golden, Colo.**

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built to connect with a recuperator and a fan which recirculates products of combustion. Preheated air mixed with about 3 volumes of products of combustion is passed back into the furnace and joins the heating gas at the burner ports. A low-temperature flame swirls around the metal tube and produces a uniform source of heat for the retort. Lignite or subbituminous coal passes through the retort in an annular space about 3 inches wide, and the products of gasification are drawn from the system through the center of the charge. Products of distillation, consisting of bed moisture, water from decomposition of the coal, tar, and hydrocarbon gases and vapors, are forced to leave the system through the hottest section of the retort. They undergo decomposition and reaction to form various grades of water gas, depending upon the temperature of the system and the concentration of steam. Carbon residues not gasified in the upper annulus pass downward into a lower annulus, where they contact steam and are gasified. The process is continuous; and gasification is carried to a point where the carbon residue, when further gasified to make producer gas, will furnish enough heat to keep the system in balance. Under these conditions, the net yield of water gas from raw subbituminous coal is 48,000 to 52,000 cubic feet per ton, and the net yield from raw lignite is 33,000 to 36,000 cubic feet per ton.

Gases of the following composition, in percent, were made from raw lignite:

| | Gas A | Gas B |
|---|---|---|
| $CO_2$ | 26.8 | 8.8 |
| Illuminants | .5 | .1 |
| CO | 8.9 | 33.8 |
| $H_2$ | 58.6 | 55.4 |
| $CH_4$ | 4.2 | 1.4 |
| $C_2H_6$ | .5 | .0 |
| $N_2$ | .5 | .5 |
| | 100.0 | 100.0 |

Water gas of the quality designated as gas A may be useful for the production of industrial hydrogen by scrubbing out the $CO_2$ and CO, and the gas indicated as gas B might be used for direct beneficiation of iron ore or for the manufacture of synthetic liquid fuels.

Table 16 gives a brief summary of the scope of tests conducted in the small pilot plant during 1945. Depending upon conditions of operation, the quality of water gas from either subbituminous coal or lignite varies considerably. The maximum capacity was reached in test 4B when making 66 cubic feet of water gas per square foot of retort surface per hour. The gas contained 3.57 parts of hydrogen to 1.0 part of carbon monoxide. In other tests, both the rate of gas generated and the rate of charging coal were varied to study the effect of various temperatures. The experimental work on the small pilot plant supports the following general conclusions:

1. Subbituminous coal or lignite can be gasified to any degree up to about 92 percent by reaction with steam at relatively low temperatures. In the present system, gases containing $H_2$:CO ranging from 1.6:1 to 12.0:1 were made by adjusting the concentration of steam when the retort was heated over the temperature range of 1,750° to 2,050° F.



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2. Subbituminous coals, because of their better physical and chemical properties are slightly easier to gasify than the lignites. However, there is little difference between the two fuels if dried to the same moisture content. Steam-dried lignite containing about 10 percent moisture appears to have better gasification properties than raw subbituminous coal.

3. The maximum capacity obtained was 66 cubic feet of gas per square foot of heated retort surface. This capacity was reached when operating the retort at an average furnace temperature of 1,720° F. while producing water gas having a $H_2$:CO ratio of 3.57 to 1. During this test, the maximum temperature at the hottest section of the furnace was 2,050° F. Under these conditions the rate of transfer of heat through the walls of the retort was approximately 4,500 B.t.u. per hour per square foot. It is indicated that higher rates can be attained by adjustment of the width of the annulus and by better distribution of temperature in the furnace.

4. Although about 92 percent of complete gasification can be attained in a single pass through the retort, it is not advisable to carry out gasification to that extent because of troubles with fine ash and resistance from the fuel bed. In commercial operation, it would be desirable to remove enough carbon or char residue for subsequent gasification in a producer to furnish heat for the externally heated retort. If this were done, it can be shown theoretically that about 10 pounds of ash-free residue, having a potential heating value of about 140,000 B.t.u., should be extracted for each 1,000 cubic feet of water gas produced. Under these conditions the net yield of water gas from a ton of raw subbituminous coal will range between 48,000 and 52,000 cubic feet per ton, whereas the net yield from raw lignite will be 33,000 to 36,000 cubic feet per ton.

5. When gasifying raw lignite with steam, the net heat passing through the walls of the retort to effect gasification is 83 to 85 B.t.u. per cubic foot of gas generated, if the products of gasification leave the retort at 1,000° F. This is the theoretical net heat required for the reaction. The heat required for gasification changes little, even though the $H_2$:CO ratio may range from 2:1 to 9:1, because the heat carried away in the excess steam increases with this $H_2$:CO ratio, whereas the heat of reaction decreases. In the Golden, Colo., pilot plant, the heating efficiency was 45 to 50 percent, requiring 164 to 190 B.t.u. to make 1 cubic foot of water gas. In a large plant where heat losses can be minimized, the heating efficiency should be about 65 percent, and the net heat required for gasification of raw lignite should be between 120 to 130 B.t.u. per cubic foot of gas made.

A commercial-size pilot plant about six times as large as the first pilot plant was built and tested during the fiscal year 1945 at Grand Forks, N. Dak.[81/] The arrangement and schematic design of this plant is shown in figure 19. The purpose of building this larger plant was to obtain data on operation and costs which could not be ascertained in the smaller unit. The plant design was about the same as the small unit, but improvements were made to increase efficiency and to streamline handling of materials. Two 10-day tests were made and the results are summarized in table 17.

81/ Chemical and Engineering News, A Staff Report, Lignite Gasification Plant Shown at Grand Forks, N. Dak.: Vol. 23, July 25, 1945, pp. 1242-1244.



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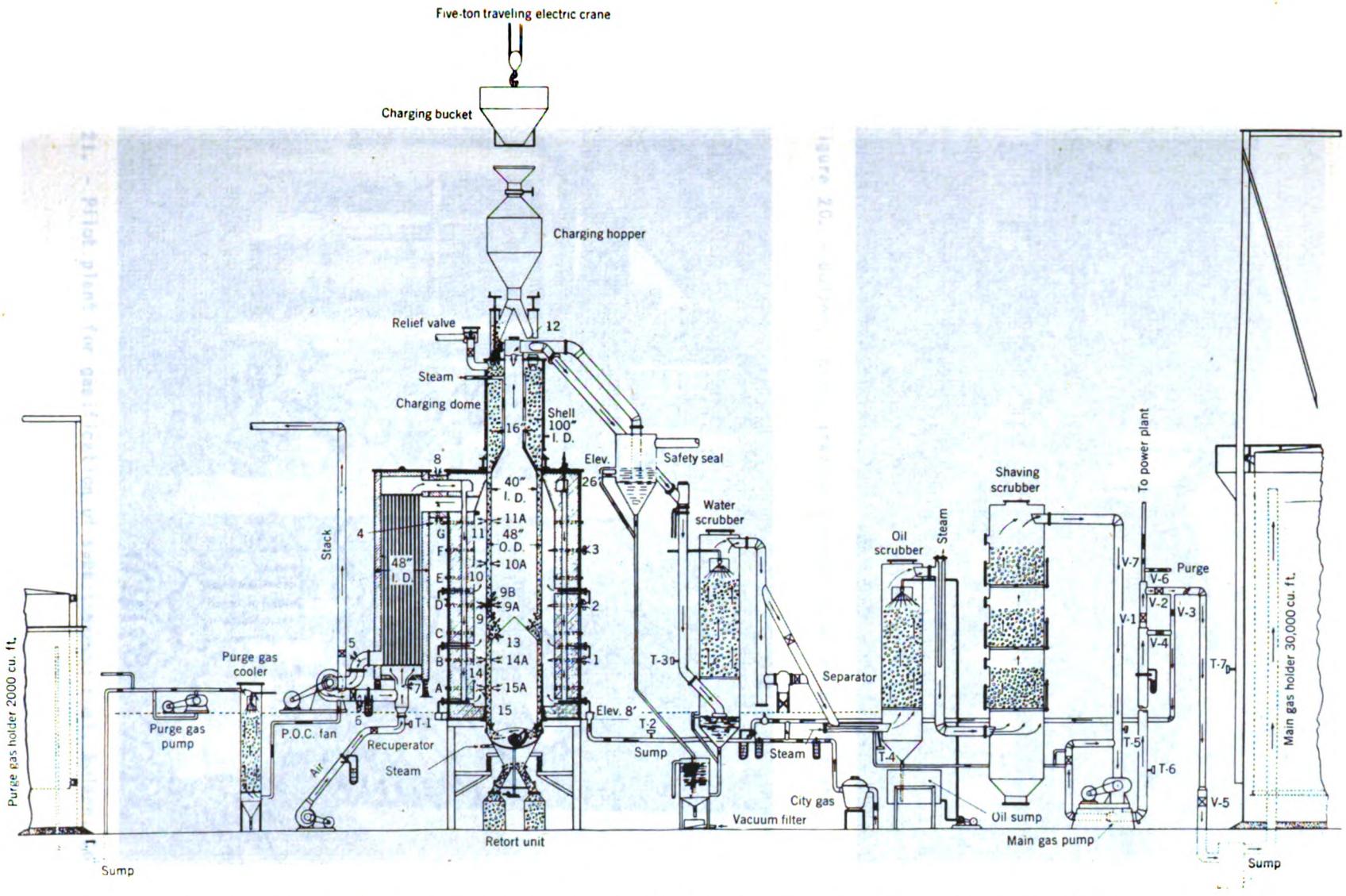


Figure 19. - Schematic arrangement and design of plant as operated during preliminary tests at Grand Forks, N. Dak., March 1945.

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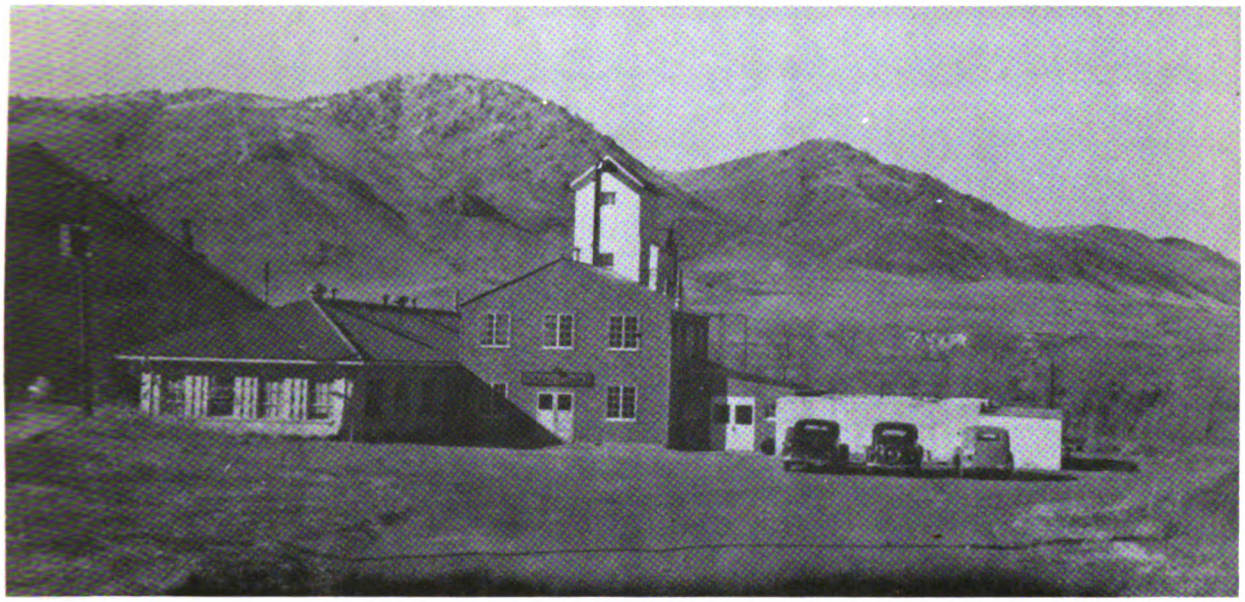

Figure 20. - Golden, Colo., station and gasification pilot plant.

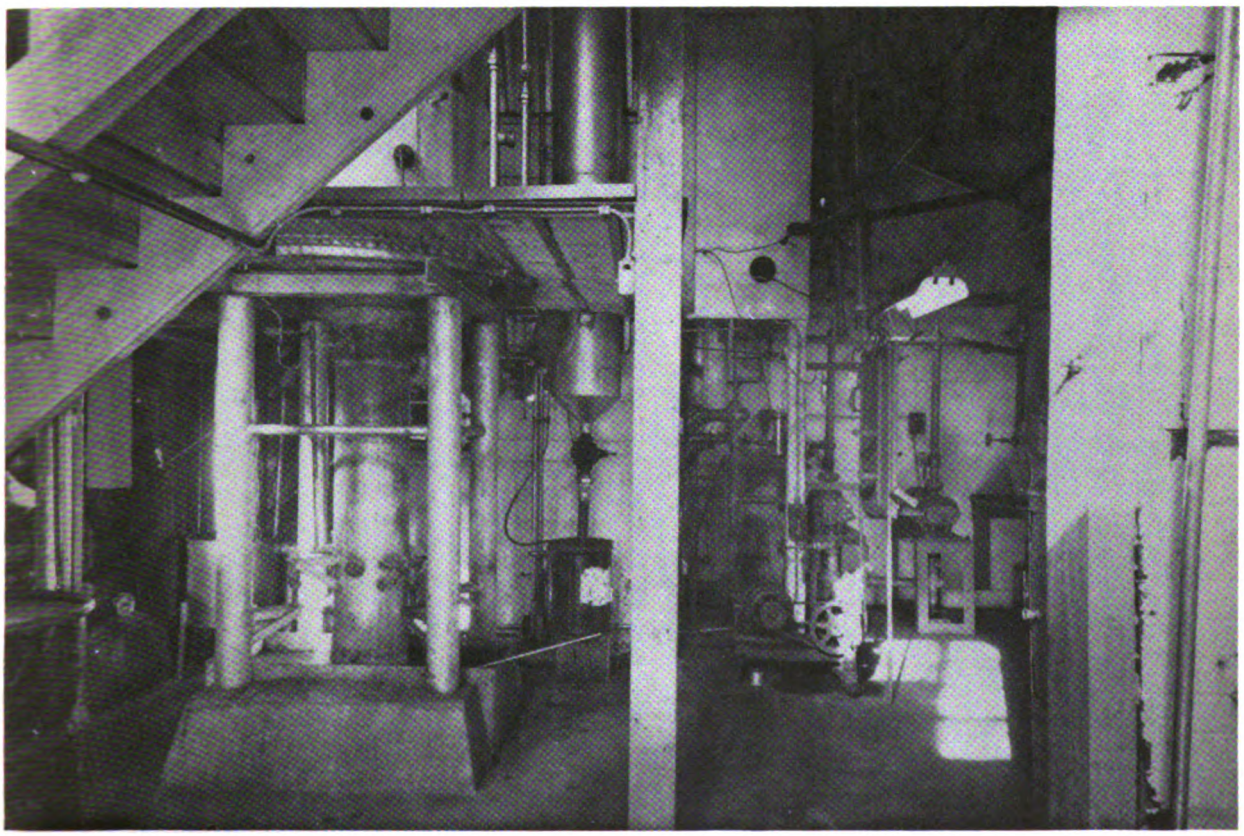

Figure 21. - Pilot plant for gasification of subbituminous coal, Golden, Colo.

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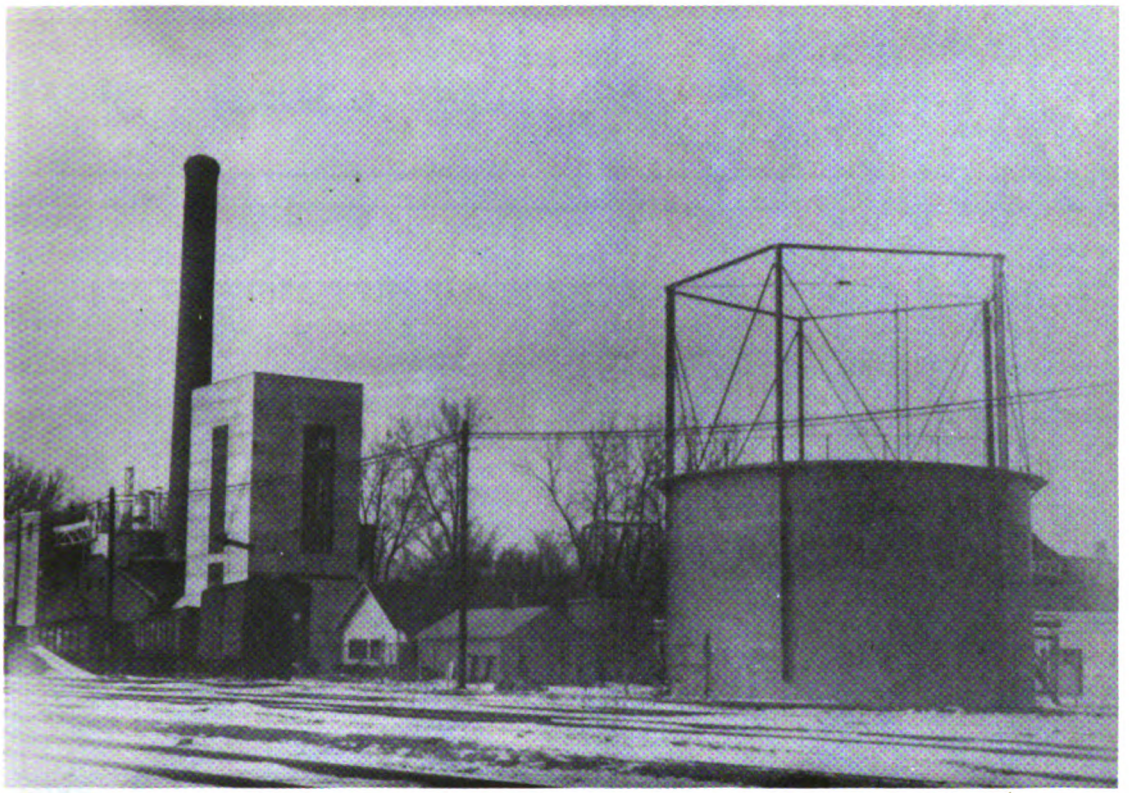

Figure 22. - Commercial-size pilot plant for gasification of lignite, Grand Forks, N. Dak.

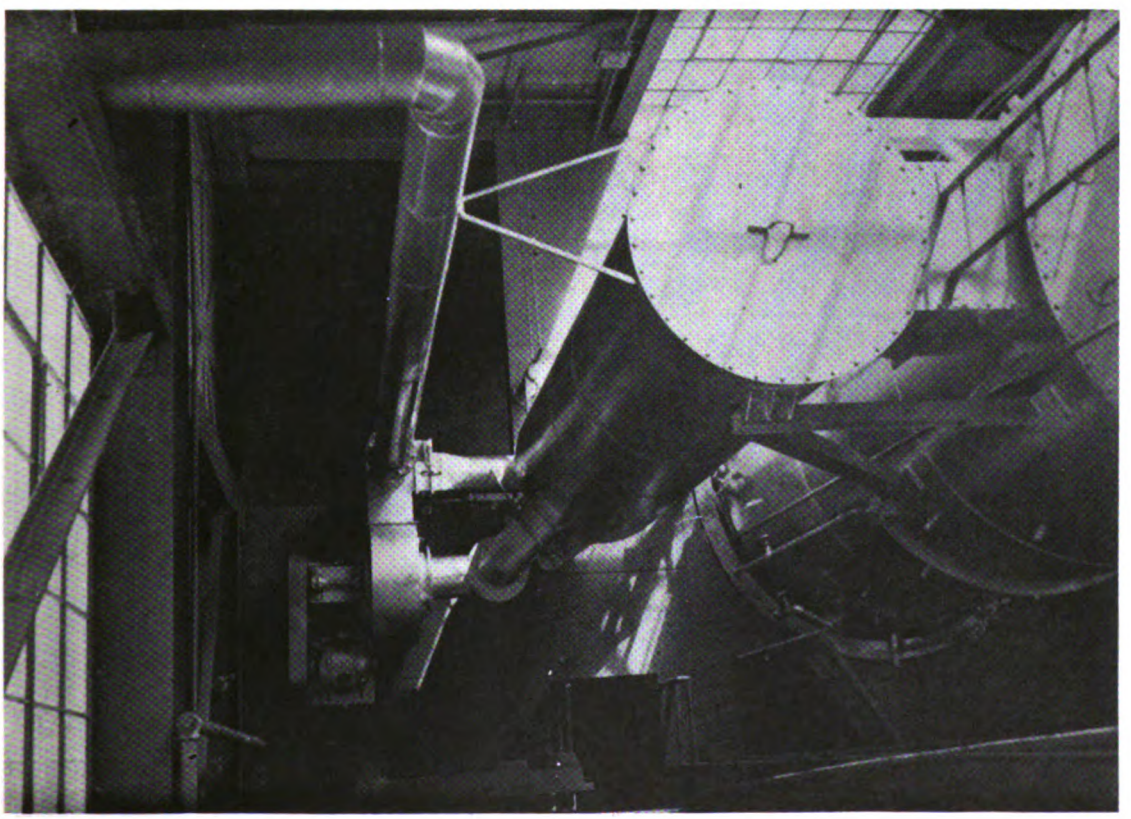

Figure 23. - Generator and recuperator of lignite-gasification pilot plant, Grand Forks, N. Dak.

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TABLE 16. - Summary of gasification tests in the small pilot plant, Golden, Colo.

| Test No. | Gas made | | | Coal charged | | Temperature of furnace | |
|---|---|---|---|---|---|---|---|
| | M.c.f. per ton | Rate[1] | Ratio $H_2$:CO | Kind | Rate[2] | °F. Maximum[3] | °F. Average[4] |
| 4A | 71.54 | 59.2 | 4.75 | Subbit. | 1.65 | 1,980 | 1,655 |
| 4B | 75.32 | 66.0 | 3.57 | do. | 1.75 | 2,050 | 1,720 |
| 5A | 68.98 | 48.1 | 4.01 | do. | 1.39 | 1,910 | 1,590 |
| 5B | 67.05 | 46.6 | 7.18 | do. | 1.39 | 1,850 | 1,540 |
| 5C | 84.37 | 50.4 | 4.73 | S. Dak. lig. | 1.20 | 1,880 | 1,605 |
| 5D | 78.59 | 50.3 | 3.28 | do. | 1.28 | 1,895 | 1,650 |
| 6A1 | - | 36.1 | 12.4 | Subbit. | - | 1,830 | 1,400 |
| 6A2 | - | 38.1 | 8.72 | do. | - | 1,855 | 1,435 |
| 6A3 | - | 39.0 | 4.42 | do. | - | 1,885 | 1,500 |
| 6A4 | - | 42.9 | 7.58 | do. | - | 1,855 | 1,510 |
| 6A1-4 | 51.10 | 38.7 | - | do. | 1.52 | - | - |
| 6B1 | - | 40.6 | 6.84 | do. | - | 1,840 | 1,485 |
| 6B2 | - | 40.3 | 9.74 | do. | - | 1,860 | 1,430 |
| 6B3 | - | 38.7 | 7.75 | do. | - | 1,840 | 1,425 |
| 6B4 | - | 41.0 | 5.48 | do. | - | 1,860 | 1,490 |
| 6B1-4 | 57.2 | 40.3 | - | do. | 1.41 | - | - |
| 7A | 58.91 | 43.7 | 11.7 | do. | 1.48 | 1,845 | 1,500 |
| 7B | 25.31 | 36.8 | 6.56 | Lignite. | 2.91 | 1,850 | 1,460 |
| 7C | 50.62 | 45.8 | 4.10 | S. Dak. lig. | 1.81 | 1,860 | 1,540 |
| 7D | 56.85 | 40.8 | 1.64 | do. | 1.44 | 2,000 | 1,510 |
| 7E | 66.74 | 47.9 | 1.97 | do. | 1.44 | 2,000 | 1,510 |
| 8A | 75.00 | 39.2 | 2.45 | Subbit. | 1.05 | 2,000 | 1,660 |
| 8B | 55.05 | 38.7 | 2.72 | Lignite | 1.41 | 2,000 | 1,690 |
| 9A | 77.31 | 32.8 | 2.41 | Subbit. | .84 | 2,000 | 1,720 |
| 9B | 70.95 | 40.9 | 3.63 | do. | 1.05 | 1,995 | 1,705 |
| 9C | 61.57 | 45.5 | 3.43 | do. | 1.48 | 2,000 | 1,700 |
| 9D | 61.78 | 50.3 | 3.04 | do. | 1.63 | 2,000 | 1,700 |

1/ Cu. ft. per hour per sq. ft. of retort area (51.0 sq. ft.).
2/ Pounds per hour per sq. ft. of retort area.
3/ At thermocouple 1.
4/ Average at thermocouples 1, 2, 3, and 4.

Photographs of the small pilot plant at Golden, Colo., and the commercial-size unit at Grand Forks, N. Dak., indicate the scope of this investigation. Figure 20 is an external view of the Golden laboratory and pilot plant, and figure 21 shows the lower section of the pilot plant with auxiliary equipment. Figure 22 is a general view of the Grand Forks plant, showing the retort building, the laboratory, and gas holders. The plant is built adjacent to the power plant at the University of North Dakota. Figure 23 is a top view of the generator in the large plant.



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TABLE 17. - Summary of results of tests on a commercial-size pilot plant for gasification of lignite, Grand Forks, N. Dak.

| | Preliminary test 1/ | | Test Number 1 2/ | | |
|---|---|---|---|---|---|
| | Period A | Period B | Period A | Period B | Period C |
| Raw lignite charged ..... pounds per hour | 600 | 639 | 598 | 681 | 540 |
| Moisture in lignite ..... percent | 37.5 | 37.5 | 37.8 | 37.8 | 37.5 |
| Ash in lignite ..... do. | 6.0 | 6.0 | 5.2 | 5.2 | 6.0 |
| Residue extracted ..... pounds per hour, dry | 153 | 159 | 152 | 152 | 138 |
| Ash in residue ..... percent | 24 | 24 | 16.3 | 15.4 | 18.0 |
| Net heating value of residue per cu. ft. of gas made .... B.t.u. | 180 | 158 | 221 | 187 | 192 |
| Gas made ..... M.c.f. per ton 3/ | 30.1 | 33.6 | 27.7 | 28.9 | 30.3 |
| Gas made ..... M.c.f. per hour 3/ | 9.02 | 10.68 | 8.26 | 9.85 | 8.17 |
| Gas made ..... cu. ft. per hr. per sq. ft. of retort surface | 41.7 | 49.5 | 38.3 | 45.6 | 37.8 |
| Analysis: | | | | | |
| $CO_2$ ..... percent | 21.4 | 20.8 | 22.4 | 23.9 | 23.5 |
| Illuminants ..... do. | .4 | .3 | .4 | .2 | .4 |
| CO ..... do. | 16.0 | 17.8 | 15.5 | 12.7 | 14.2 |
| $H_2$ ..... do. | 55.5 | 55.7 | 56.6 | 58.2 | 57.1 |
| $CH_4$ ..... do. | 4.8 | 4.5 | 3.7 | 4.2 | 3.9 |
| $C_2H_6$ ..... do. | .0 | .0 | .9 | .3 | .4 |
| $N_2$ ..... do. | 1.9 | .9 | .5 | .5 | .5 |
| Heating value ..... B.t.u. per cu. ft. | 281 | 282 | 289 | 280 | 280 |
| Net heat used ..... B.t.u. per cu. ft. of gas made | 144 | 151 | 138 | 130 | 128 |
| Steam used ..... total pounds per pound of lignite | .66 | .92 | .67 | .83 | .35 |
| Temperature of steam ..... °F. | 212 | 212 | 435 | 455 | 495 |
| Temperature of furnace at hottest part ..... do. | 1,980 | 1,995 | 1,815 | 1,805 | 1,800 |
| Average temperature of furnace ..... do. | 1,826 | 1,884 | 1,705 | 1,670 | 1,695 |
| Temperature of gases leaving retort ..... do. | 600 | 645 | 615 | 605 | 580 |
| Ratio, products recirculated to primary air ..... | 2.62 | 2.6 | 3.0 | 2.7 | 3.3 |

1/ In this test length of upper annulus was 10 ft. 2 inches and bottom annulus was 6 ft. 1.0 inch.
2/ In this test length of upper annulus was 13 ft. 2 inches and bottom annulus was 5 ft. 0.0 inch.
3/ Gas saturated with water vapor at 60° F. and under 30 inches of mercury pressure.



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## Mineral Wool from Rhode Island Anthracite

In cooperation with the Rhode Island State College, a study was made of the suitability of Rhode Island anthracite for the direct production of mineral wool. Characterized by an ash content usually over 30 percent and with low reactivity because of its high content of graphite, this material has been considered unsuited for use as fuel. These properties, however, are desirable for the manufacture of mineral wool, and this application is considered to be most promising in developing a market for this material. Experimentation will be conducted in a slagging gas producer having an inside diameter of 21 inches, thus approaching in size the smaller cupolas already used for manufacturing mineral wool. The investigation will include as objectives not only the production of a commercial quality of mineral wool, including a study of the local materials available as fluxes, but also the generation of useful producer gas as a byproduct.

## Use of Barley-Size Anthracite in Gas Producers

To permit the substitution of Barley- for Rice-size anthracite in gas producers, experiments made with the use of a fuel-bed agitator showed that Barley-size anthracite could be gasified at approximately one-half the normal rate attainable with Rice-size anthracite when no agitator was used.[82/] Higher rates were not obtainable, mainly because the center of the fuel bed was weak. A method of feeding the producer fuel so as to permit a deeper center is expected to remedy the troubles due to thickness, shape, and heating conditions of the fuel bed.

## Carbon Monoxide Generator

For use in a proposed small-scale Fischer Tropsch experimental plant, a carbon monoxide generator was developed utilizing pitch coke or petroleum coke as fuel and having an oxygen blast. The raw gas leaving the generator contains approximately 97 percent carbon monoxide, 1.6 percent nitrogen, 1 percent hydrogen, and 0.5 percent carbon dioxide and oxygen. Most of the ash in the fuel is volatilized and present in the gas as a "smoke," necessitating electrical precipitation methods for cleaning. Although the experimental unit had a capacity of 25,000 cubic feet per day of carbon monoxide, extension of the same principle to larger units having greater capacity seems warranted.

# LIQUEFACTION

## Literature Reviews and Abstracts

Comprehensive reviews of technical publications and patents which appeared before 1941 on synthetic liquid fuels processes were published as chapters of a new two-volume book entitled "Chemistry of Coal Utilization."

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82/ See footnote 66.



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One of these chapters[83] summarizes the industrial development of the hydrogenation of coal and tar, and gives a critical discussion of the important physical chemical factors involved in the liquefaction of coal by hydrogenation. Results of industrial operations and of laboratory investigations on the influence of rank and of type of coal, pretreatment of coal, nature of solvent or vehicle, importance of vehicle, agitation, and catalyst, effects of temperature, pressure, and contact time, characteristics of oils produced in liquid-phase hydrogenation, hydrogenation of coal tar, and the design and materials for construction of coal- and tar-hydrogenation equipment were comprehensively reviewed.

A second chapter[84] deals with the synthesis of hydrocarbons from water gas. Industrial developments, methods of production of synthesis gas and of hydrogen, mechanisms of the reactions, factors involved that affect the composition and yield, properties of Fischer-Tropsch products, and the economics of coal and carbon monoxide hydrogenation were thoroughly reviewed.

Another chapter[85] discusses the methanol synthesis from water gas. Processes of manufacture, determination of the methanol equilibrium, methanol-process patents, production and purification of hydrogen and of carbon monoxide, apparatus for methanol synthesis, methods of purification of methanol, and catalysts used in its synthesis were comprehensively examined.

A critical review of the fundamental chemistry of destructive hydrogenation of coal, coal tar, and oil, and of the synthesis of hydrocarbons from water gas was published.[86]

A bibliography of Bureau of Mines investigations on the production of liquid fuels from oil shale, coal, lignite, and natural gas was compiled.[87] In addition to the publications issued by the Government in printed or mimeographed form, references are included to articles written by Bureau of Mines staff members for the technical press and to cooperative reports of work done jointly with States, colleges, and industries. The bibliography lists a total of 231 publications and 5 patents.

A systematic abstracting service was organized for reviewing current literature on synthetic liquid fuels and related subjects. These abstracts

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83/ Storch, H. H., Hydrogenation of Coal and Tar: Nat. Research Council (H. H. Lowry, ed.), Chemistry of Coal Utilization, New York, vol. 2, pp. 1750-1796.

84/ Storch, H. H., Synthesis of Hydrocarbons from Water Gas: Nat. Research Council (H. H. Lowry, ed.), Chemistry of Coal Utilization, New York, vol. 2, 1945, pp. 1797-1845.

85/ Hirst, H. H., Methanol Synthesis from Water Gas: Nat. Research Council (H. H. Lowry, ed.), Chemistry of Coal Utilization, New York, vol. 2, 1945, pp. 1846-1868.

86/ Storch, H. H., Catalysis in Synthetic Liquid-Fuel Processes: Ind. Eng. Chem., vol. 37, 1945, pp. 340-351.

87/ Fieldner, A. C., and Fisher, P. L., Bibliography of Bureau of Mines Investigations on the Production of Liquid Fuels from Oil Shale, Coal, Lignite, and Natural Gas: Inf. Circ. 7304, 1945, 18 pp.



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cover a wide range of pure and applied science and are of value not only to the Synthetic Liquid Fuels Office, but also to the Coal, Explosives, and Petroleum and Natural Gas Divisions of the Fuels and Explosives Branch. Exhaustive patent surveys on synthetic liquid fuel processes are in progress and will be completed and ready for publication during the next year.

## Inspection of Synthetic Liquid Fuel Plants in Germany

Five members of the staff of the Office of Synthetic Liquid Fuels were sent to Germany where they spent 2 to 3 months in inspecting synthetic liquid fuel plants, examining documents containing technical information, and interrogating key personnel connected with the plants. Reports on these activities will be made through the Petroleum Administration for War. All of the commercial-size plants were 1938 models. Some interesting and potentially important laboratory and pilot-plant research data were found.

## Reaction Mechanisms in Hydrogenation of Coal

The products obtained by the hydrogenation of coal are, in part, assumed to be present in the original coal structure and to be formed by the depolymerization of the coal. An interesting possibility is that some of the condensed aromatic nuclei obtained during the hydrogenation of coal result from less highly cyclic structures by the thermal or catalytic intramolecular loss of hydrogen. Such transformations might occur by the loss of hydrogen from two suitably situated methyl groups or from a methyl group and an aromatic nucleus. It was found[88] that when 2,2'-dimethylbiphenyl is repeatedly passed over a palladium-charcoal catalyst at 450° C. it is converted to 4-methylfluorene (a three-ring aromatic). A similar reaction starting with methylbiphenyl gave fluorene[89] and with dinaphthyl gave perylene. Cyclodehydrogenation of dimesityl was unsuccessful, which indicates that the pyrene nucleus may be present in the original coal. Byproducts of this research work consisted in the synthesis of about 10 new organic compounds needed as intermediates and in a new design of a useful dropping funnel.[90]

Many data on various research problems concerned with the hydrogenation of coal were collected during the year. These data are in a preliminary "progress-report" stage; and upon the accumulation of more data and critical reviews thereof, publications on these research programs will be made.

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88/ Orchin, M. and Woolfolk, E. O., Aromatic Cyclodehydrogenation. I. 4-Methylfluorene from 2,2'-Dimethylbiphenyl: Jour. Am. Chem. Soc., vol. 67, 1945, pp. 122-124.

89/ Orchin, M., Aromatic Cyclodehydrogenation. II. A New Synthesis of Fluorene: Jour. Am. Chem. Soc., vol. 67, 1945, p. 499.

90/ Orchin, M., Modified Dropping Funnel: Ind. Eng. Chem., anal. ed., vol. 17, 1945, p. 99.



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